# THE IMPACT OF ENVIRONMENTAL FEATURES ON BEEF CATTLE BEHAVIOR, PHYSIOLOGY, PERFORMANCE AND HEALTH

A Thesis

by

RACHEL MEREDITH PARK

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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| Chair of Committee, | Courtney Daigle |
| Committee Members, | Reinaldo Cooke |
| | Andy D. Herring |
| Head of Department, | Graham C. Lamb |

May 2019

Major Subject: Animal Science

## ABSTRACT

Two separate experiments were conducted to further understand beef cattle welfare. The first experiment (e.g. systematic review) sought to answer the question "How do housing facility features impact the status of animal welfare of beef cattle?" From 1,147 citations, 40 studies were included that evaluated the impact of a feature of beef cattle housing on welfare. Housing features were categorized by floor type, space allowance, shade availability, and inclusion of enrichment devices or ventilation features. The second experiment evaluated the impact of environmental enrichment (EE) on cattle stress physiology, health, productivity and behavior. The EE consisted of an L-shaped brush structure mounted to the fence line furthest from the feed bunk. Fifty-four crossbred steers were randomly assigned to one of two treatments 1) No enrichment (CON) or 2) Enrichment (BRUSH). Hair coat shed scores were recorded upon arrival at the feedlot (d -55) and prior to shipment of first weight block (d 161) for slaughter using an objective scoring system. Body weights and hair samples for cortisol extraction were obtained at 35-d intervals throughout the duration of the study. Average daily gain, G:F and weekly DMI were calculated. Upon slaughter, carcass data were collected. Decoded video recordings measured the frequency and duration of behaviors for 9.5 hours on d -2, -1, 0, 1, 2, 4, 8, 16, 32 and 64 relative to brush installation using both continuous and scan sampling. Impact of day, treatment and their interactions were evaluated using PROC MIXED in SAS. Treatment did not impact steer stress physiology, feed efficiency or carcass traits ($P > 0.05$). BRUSH cattle performed fewer headbutts ($P = 0.006$), engaged in bar licking less frequently ($P = 0.009$) and for a shorter duration ($P = 0.035$) compared to CON cattle. For BRUSH cattle, frequency and duration of brush usage changed over time peaking on d 0 ($P < 0.001$). BRUSH cattle performed fewer stereotypic and aggressive behaviors and cattle did not habituate to the brush over time. Presence of a cattle brush did not negatively impact production or physiology of the animals. A cattle brush would be beneficial to feedlot cattle welfare.

## DEDICATION

To the woman who passed on her love and passion for animals to me – my mother, my angel and best friend, Rebecca Park.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Courtney Daigle, for her constant encouragement, guidance throughout the course of this research, and affording me opportunities to learn and grow as an animal scientist. Her door was always open to me and I am thankful to have had the ability to learn under her. To my committee members, Dr. Reinaldo Cooke and Dr. Andy Herring, thank you for your guidance and support throughout the course of this research and writing process. Margaret Foster contributed invaluable help with the systematic review process and I am incredibly appreciative for her advice. Thank you to Dr. Cliff Lamb for his encouragement of my endeavors throughout my time here at Texas A&M University. Additionally, I am profoundly grateful to Dr. Monique Pairis-Garcia and Dr. Proudfoot for introducing me to animal welfare and providing me with countless opportunities during my undergraduate career that laid the foundation for my future success in research and life.

My research would not have been possible without the following students from the Animal Behavior and Welfare Laboratory - Daniel Aberra, Alexandra Allen, Anabelle Cope, Samuel Couch, Andrew Deleon, Carley Devillier, James Everhart, Crystobal Garza, Makala Herman, Victoria Kamilar, Adelle Langcauon, Amy Larsen, Everett Lowenstein, Marina Maale, Xandra Meneses, Theresa Nelson, Logan Papinchak, Sarah Rico, Emily Ridge, Daniella Romero, Logan Roper, Katlin Stone, Sydney Tejml, Taylor Thompson, Jaquelyn Trevino and Stephanie Young. I appreciate each and every one of you for your dedication and passion towards this research and am grateful to have had the opportunity to teach you.

Lastly, I would like to thank my family and friends for their constant support throughout this graduate degree. Thank you to my mother for her love that has fueled my dedication towards animal welfare. Without her, I would not be where I am today. To my grandmother, father, brothers and Heidi – I am grateful for your encouragement. Diane Makebakken, Kathy Scott, Melissa Froman and families, thank you for treating me like one of your own and ensuring that I always knew that I had your love and support to fall back on. Thank you to my all of my fellow graduate students and close friends for always being available to share ideas, laughter, tears and drinks with. I am especially grateful to Kelsey Schubach for teaching me new laboratory techniques, her mentorship and more importantly, for her close friendship. Thank you to my academic sister, Emily Ridge, for being by my side through research, travel, teaching and life. Finally, I would like to thank my loving partner, Anthony Caddiell, for being my rock throughout this experience. Your constant love and support is instrumental in my success and I cannot thank you enough for being a constant reminder of what is important in life.

CONTRIBUTORS AND FUNDING SOURCES


**Contributors**

This work was supervised by a thesis committee consisting of Dr. Courtney Daigle (Advisor) and Dr. Reinaldo Cooke of the Department of Animal Science and Dr. Andy Herring of the Department of Animal Science, as well as the Department of Genetics. All work conducted for the thesis was completed by the student independently.

**Funding Sources**

Texas A&M University Department of Animal Science financially supported this work through the Mini Grant Program.

NOMENCLATURE

| | |
|---|---|
| ACTH | Adrenocorticotrophic hormone |
| ADF | Avoidance distance at feedrack |
| ADG | Average daily gain |
| BCS | Body condition score |
| CV | Coefficient of variation |
| DMI | Dry matter intake |
| EE | Environmental enrichment |
| G:F | Gain to feed ratio |
| HCW | Hot carcass weight |
| KPH | Kidney, pelvic and heart fat |
| REA | Rib eye area |

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# 1. INTRODUCTION

Beef cattle housing varies based upon specific producer needs and stage of production. Factors influencing these choices include country, region, politics, culture, legislation, social norms and personal preferences of the producer. Housing systems and their potential features (e.g. flooring type, space availability, shade access, enrichment and ventilation) impact the overall welfare status of the animals maintained in these environments. Therefore, a synthesized piece of literature is needed to review the impact of housing features on beef cattle welfare, which is the aim of the systematic review included.

Cattle in the finishing stage of production are often maintained in feedlots to maximize space and management efficiency. However, the feedlot environment lacks interactive features inhibiting the performance of select behavioral patterns that cattle would perform in an extensive setting. Animals that do not have the ability to interact with their environment and are maintained in an environment that lacks mental stimulation may experience boredom which can lead to the performance of destructive, agonistic and stereotypic behaviors (Wood-Gush et al., 1983; Mason and Latham, 2004).

Enhancing the animal's environment through increasing the diversity of stimuli that animals may engage with has been demonstrated to enhance their welfare through promoting expression of highly motivated behaviors (Pelley et al., 2005, Kohari et al., 2007). The implementation of environmental enrichment (EE) is described as the effort to improve biological functioning or the quality of life for an animal by providing environmental stimuli that promotes the performance of species appropriate behaviors (Newberry, 1995; Fraser, et al., 1997; Reinhardt & Reinhardt, 2003).

Cattle have an internal motivation to express an extensive range of grooming behaviors; however, in a feedlot setting, cattle cannot perform these behaviors to their full extent (Wilson et al., 2002). While these animals are able to self-groom and groom their conspecifics, they lack access to an inanimate object to groom with which is a distinct grooming motivation (Kohari et al., 2007). Previous research on feedlot cattle has indicated a preference for a grooming device as a form of EE compared to scent releasing devices (Wilson et al., 2002). Additionally, research on dairy cattle has determined that cattle use brushes and do not habituate to them over time (DeVries et al., 2007; Newby et al., 2013). Therefore, the implementation of species specific EE (a cattle brush) in the present study has the potential to mitigate boredom in feedlot cattle, as well as enhance animal performance and health status.

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# 2. A SYSTEMATIC REVIEW: THE IMPACT OF HOUSING SYSTEMS AND ENVIRONMENTAL FEATURES ON BEEF CATTLE WELFARE

## 2.1. Introduction

Beef cattle housing varies based on stage of production, country, region and personal preferences of the producer. Veal calf, cow-calf, stocker and feedlot operations differ in their production goals, as well as the breed and age of cattle managed. These inherent differences among operations require that cattle housing vary based on the specific needs of the producer. Across the globe, politics, legislation, social norms and perceptions of beef cattle differ thus impacting housing decisions made by producers. Unique to beef cattle production, compared to pork, poultry and dairy industries, is that environmental conditions and climate are highly variable across the beef production system, therefore, these factors must be considered with regards to housing.

The environments that beef cattle will experience vary based upon the type of housing system used as well as in the various available features within these housing systems (e.g. flooring type, space availability, shade access, enrichment and ventilation). Housing features create the environments and microclimates that cattle experience. The intensity, variation and type of environments created can have a direct impact on animal health, productivity and welfare. Therefore, evaluating how these housing differences impact the animal (e.g. behavior, physiology and productivity) will facilitate understanding of the welfare status of the animals maintained within each specific system.

Reviews relative to beef cattle housing have been limited. Ingartsen and Anderson (1993; 1) examined the relationships among space allowance, housing type and flooring on performance of cattle. Production measures examined included daily gain, feed intake, feed conversion, dressing percentages, carcass composition and conformation score. However, their review did not assess measures that may provide more insight into the welfare status of the animals under varying housing conditions, as the sole focus of comparison was on performance metrics.

Several reviews specifically examined flooring materials in beef cattle production (2, 3, 4). Tuyttens (2005; 2) investigated the impact of straw on dairy and beef cattle comfort, preference, hygiene and nutrition in a pen barn system for reproductive females, veal calves and fattening beef cattle. Weschler (2011; 3) compared floor quality, as well as space allowance on indoor housed finishing cattle lying behavior, preference, leg lesions, claw health, mortality, cleanliness, growth performance, tail tip lesions and physiological (cortisol and ACTH) measures. Similarly, Keane et al. (2018; 4) conducted a meta-analysis investigating the impact of flooring type on indoor housed finishing cattle lying time, dirt scores, gain, feed conversion and carcass weights. To the authors' knowledge, this is the first review that is systematic in nature that emphasizes the impact of housing on cattle welfare.

A systematic analysis of scientific peer-reviewed literature is necessary to gain more insight into the relationship between beef cattle housing and beef cattle welfare status. The review question agreed upon for this paper was "How do housing facility features impact the status of animal welfare of beef cattle?" There were three main objectives of this review. The first aim of this review was to create a catalog of the housing systems, as well as the features of housing that producers have used throughout the various stages of beef production to characterize the advantages and disadvantages of the different housing options' impact on beef cattle welfare. Secondly, the review was used to assemble measures that have been used to assess beef cattle welfare in housing studies. Lastly, the relationships between housing and beef cattle welfare status were examined.

## 2.2. Materials and Methods

### 2.2.1. Eligibility Criteria

The population considered for this systematic review consisted of beef cattle. All stages of production were included. Studies were required to examine housing as the intervention with the animal's well being as an outcome. The following definitions of terms were used:

1. Housing facilities: Pastures and/or buildings used to confine beef cattle for food production
2. Features of housing: Features of the housing units such as space allowance, flooring, shade, enrichment additions and/or ventilation
3. Animal welfare: How the animal is coping in the conditions in which it lives

Studies were included from the following years: 1975 to 2018. Consideration was given to randomized control studies. Only papers written in English were considered for inclusion.

### 2.2.2. Search

Four databases were searched: CAB Abstracts (Ovid), AGRIS (Ovid), Agricola (Ebsco), and the Searchable Proceedings of Animal Conferences. Concepts included in the search were beef cattle, housing and welfare. Concepts were searched in keyword, thesaurus, title and abstract fields following the Cochrane Collaboration standards of search strategy structure. Searches were conducted between December 8, 2017 and April 11, 2018. Cab Abstracts was updated on June 4, 2018. See Table 2.1 for the details of the search.

Citations were uploaded to Rayyan QRCI to be sorted for inclusion on the basis of title and abstract content (5). One reviewer read all abstracts to identify potentially relevant studies. These studies were then uploaded into RefWorks Proquest for full text to be acquired and reviewed. One reviewer read all full articles to determine study inclusion in the systematic review.

### 2.2.3. Coding and Appraisal

A standardized form was used to extract data from studies that were determined to be relevant to the research topic. This form was designed to gather the following information: characteristics of the population, treatment details, features of the housing systems, types of measures recorded and outcomes. Only outcomes relevant to behavior, physiology and production were gathered in an attempt to gain a better overall understanding of the welfare status of the cattle on trial. The significance level used for this paper was $P < 0.05$, as reported in original studies. In the event that a measurement was significant, the level of significance was recorded. Four reviewers extracted the data at this stage of the process. The extraction process was piloted by having all reviewers code one study. Results were discussed after to ensure accuracy in data extraction between all reviewers. The remaining studies were divided equally and randomly assigned to one reviewer to code. The Cochrane Risk of Bias tool was used to determine any biases within the studies that were selected. A standardized form was created to assess each study. Two reviewers completed the form for each study. Reviewers assessed all studies therefore, any disagreements in results were discussed between reviewers and a decision was determined that most accurately represented the study.

**2.3. Results**

From the search, 267 citations were found from three different databases (CAB, AGRIS and Agricola) while 880 citations were found from other search approaches. In total, 1,147 non-duplicate citations were screened for this systematic review. After conducting search and study selection, 40 studies were selected for inclusion. See PRISMA flowchart for numbers (Figure 2.1).

Studies spanned across five different continents with the majority conducted in Europe (26 studies) and North America (8 studies), followed by Asia (3 studies), Africa (2 studies) and Australia (1 study). Experimental length of studies ranged from 22 days to 2 years with two studies not providing their timeline. The majority of studies evaluated focused on the fattening stage (37 studies) with the remainder concentrating on veal calves (2 studies) and cow-calf (1 study). These studies housed cattle in the following systems: feedlot pens (34 studies), pasture (6 studies), barns (4 studies) or crates/pens (2 studies). Studies were grouped into what feature of housing they evaluated which included the following: floor type (17 studies), housing system (8 studies), shade (8 studies), space allowance (6 studies) or miscellaneous (4 studies; enrichment – 2 studies, roofing and ventilation).

The number of animals per study ranged from 8 to 2700 with the average amount of animals used being 318. Cattle used in these studies consisted of over 30 breeds with eleven studies evaluating cattle that had Charolais influence. Animals ranged in age from < 1 year to 7 years with the majority of studies utilizing animals < 1 year of age and 18 studies not identifying the age of their cattle. The majority of studies evaluated bulls (17 studies) or steers (14 studies) followed by heifers (14 studies), veal bull calves (2 studies) and cows (1 study; Table 2.2).

### 2.3.1. Measures

Over 232 various measures were recorded across the 40 studies. These measures were grouped according to what they aimed to assess with 82 behavioral measures, 31 health measures, 67 physiological measures and 52 production measures. The measures discussed below were identified by the author of the systematic review as pertinent to beef cattle welfare evaluation with regards to housing (Table 2.3). Due to the number of measures, only those with significant results were included in Table(s) 2.4, 2.5, 2.6, 2.7 and 2.8. Three studies did not have significant findings or presented findings in a manner that results were not able to be synthesized and therefore will not be discussed further in this review (6, 7, 8).

### 2.3.2. Housing Systems

There were eleven different housing systems evaluated from eight separate studies (Table 2.4). Cattle housed in tie-stalls had reduced welfare compared to those in loose housing as is reflected in greater concentrations of physiological indicators. Veal calves experienced negative behavioral, physiological and performance consequences when housed in individual wooden crates paralleled to group pens. Significant findings indicated negative impacts on cattle behavior for animals housed in a confined feedlot compared to having access to pasture or being raised in pasture, as well as in comparison to cattle housed in a hoop barn. However, pasture cattle seemed to have mixed welfare consequences, demonstrated through physiological indicators, compared to the same feedlot situations previously mentioned. Cattle housed in a loose barn compared to pasture excelled in some areas of welfare as indicated through performance and physiological based measures, however, had mixed behavioral responses.

### 2.3.3. Space Allowances and Flooring

A comparison of space allowance demonstrates a trend that the lower amount of space provided resulted in negative welfare consequences whereas the greater amount of space provided resulted in positive welfare consequences. There is an exception to this when examining cattle provided $3.0m^2$ per animal compared to those provided $1.5m^2$ per animal as these cattle revealed mixed indicators of animal welfare (Table 2.5). In total, 17 studies examined flooring type as a feature of housing beef cattle. Across these studies, 19 different flooring types were evaluated (Table 2.6). Fourteen of these flooring types were examined in only one study each. A fully slatted concrete floor was the most examined flooring option and was compared to 12 different flooring types across 11 different studies. Fully slatted rubber flooring and deep litter were the next most examined flooring options being used in four different studies, respectively.

### 2.3.4. Shade and Miscellaneous Housing Features

Studies evaluating shade were examined to determine the benefits and drawbacks of this intervention (Table 2.7). An abundance of the results supported the implementation of shade as having a positive impact on beef cattle welfare through a combination of behavioral, physiological and performance indicators. The remaining studies varied in housing features evaluated including enrichment devices, roofing types and ventilation. Primarily these interventions had positive or neutral impacts on the cattle studied. For example, when tested for preference, cattle provided a brush device interacted with this type of enrichment the most frequently and for the longest duration of time (Table 2.8). Cattle provided enrichment had no observed negative impacts on health or performance variables.

### 2.3.5. Cochrane Risk of Bias

Only randomized controlled trials were reviewed as to assess for risk of bias. All studies were evaluated utilizing the Cochrane Risk of Bias tool by two researchers (9; Figure 2.2). No studies were removed from the review due to their results from the Cochrane Risk of Bias analysis. All beef cattle housing studies selected excelled in reporting results on all measures obtained, as well as ensuring that animals assigned to the control treatment are assessed on the same outcomes as animals provided the treatment(s). However, these same studies failed to blind the animal caretakers to the treatment assignment. All studies were unclear whether the person enrolling cattle into treatments was aware of the allocation sequence. Studies varied with regard to how animals were randomly allocated to treatments and whether there were deviations in data due to removal of animals from specific treatment groups.

**2.4. Discussion**

Housing systems vary within the beef cattle industry by stage of production and production outcome. Cattle in the finishing phase that were housed in a loose barn environment had both advantages and disadvantages to their welfare when compared to cattle housed on pasture. Cattle housed in the loose barn had greater final live weights, ADG and BCS (10). Loose barn housed cattle also performed fewer mounting events (11), spent less time vocalizing (10), spent less time walking (10, 11) and spent more time engaged in lying behavior (11). However, loose barn housed cattle spent more time standing (10), engaging in agonistic interactions (10), and performing oral explorative and oral manipulative behaviors (10, 11). Stravaggi Cucuzza et al. (2014; 12) conducted a study to compare loose housing to tie-stall housing. His research group demonstrated that tie-stall housing was stressful to cattle in the fattening stage as animals housed in a tie-stall barn had greater levels of total serum protein, serum lysozymes, fecal corticosterone, serum corticosterone and cortisol. From these findings, loose housing was considered more favorable in comparison to tie-stall housing.

Studies examining feedlot housed cattle observed a negative impact of housing system on cattle behavior as cattle in the feedlots engaged in agonistic behaviors more frequently and for longer durations (e.g. headbutting, pushing, displacement; 13) compared to cattle with access to pasture. Similarly, feedlot housed cattle spent more time standing and walking, as well as engaged in lying for a shorter duration of time paralleled to cattle housed in a hoop barn (14). Environmental enrichment implementation may be an effective behavioral intervention for feedlot producers as this may allow for a greater display of the cattle's behavioral repertoire and increase their welfare status. Although studies were limited that examined veal calf housing, the findings provided overwhelming support for group housing compared to individual crates. Housing veal calves in groups resulted in a greater expression of social behaviors (15), a reduced expression of stereotypic behaviors (16) and improved carcass traits (16).

Cattle can benefit from an increased space allowance in the feedlot. Feedlot environments that provided animals with $3.0m^2$ to $4.5m^2$ per animal had greater live weight gains (17), as well as greater ADG (18) and a lower kill out proportion (19). These animals performed a greater amount of positive social behaviors (17), spent a higher percentage of their day lying (20) and performed fewer abnormal behaviors (20). However, Fisher et al., (1997; 17) found that cattle housed at a density of $3.0m^2$ per animal compared to those in an environment of $1.5m^2$ per animal had a greater mean- and peak-ACTH cortisol concentration. The authors of that study hypothesized that animals housed in the $1.5m^2$ per animal housing were restricted in movement and therefore exposed to chronic overcrowding which may have resulted in adrenal fatigue (e.g., a reduction of responsiveness in the adrenal gland to ACTH). Overall, feedlots that provided cattle with $1.5m^2$ per animal fared the poorest. Cattle in this setting spent less time lying (17, 19, 21) indicating a decreased comfort state, as this behavior is important to cattle welfare and productivity. Hickey et al. (2003; 19) determined that highly stocked cattle did not interact socially as often as cattle with greater space allowances. High stocking density also had a negative impact on productivity and performance. Cattle that were provided 1.5m$^2$ per animal had reduced final body weights (21) and ADG (21), and also had higher feed conversion ratios (19), as well as greater kill out proportions (17, 21). Therefore, housing cattle with a space allowance of 1.5m$^2$ per animal is not recommended, particularly for indoor housed cattle. The findings from these studies indicate that the difference between providing 2.5m$^2$ per animal to 3.0m$^2$ per animal could be substantial regarding the improvement of cattle welfare. However, there is not a clear understanding, as to when increasing space allowances no longer provides additional benefits.

Rearing cattle for fattening in a feedlot requires consideration for how flooring surfaces impact cattle welfare. Concerns have been raised regarding the use of fully slatted concrete floors as this flooring type has been viewed as suboptimal for the animals' welfare needs (22). This claim is partially supported by the findings of this systematic review. Cattle housed on fully slatted concrete floors performed greater frequencies of abnormal behaviors (20), had more unsuccessful lying attempts (23) and had a higher prevalence of health issues (e.g. skin lesions, locomotor disorders) (23, 24) in comparison to fully slatted rubber mats. Fully slatted rubber mats resulted in greater live weight gains (23, 25), ADG (23, 25), lower feed conversions (25) and fewer health issues (20, 26). However, cattle housed on fully slatted rubber mats performed more agonistic behaviors compared to those on fully slatted concrete floors (23). Animals housed on fully slatted concrete floors, as well as animals housed on fully slatted rubber mats, display mixed results in comparison to specific mat conditions (e.g. foam structure rubber, natural rubber structure, partial cover of a solid mat, etc.) displaying both welfare advantages and disadvantages as indicated through behavioral, performance and health measures. For further detail, see Table 2.6. Cattle housed on straw had a greater frequency of lying behavior (20), improved hygiene scores (27) and enhanced performance measures (e.g. improved feed conversion ratio, higher ADG, greater carcass weight; 18). These results suggest that cattle housed on straw floors had an enhanced welfare state compared to those housed on flat concrete, fully slatted concrete and fully slatted rubber mats. This review highlights that there are advantages and disadvantages to cattle welfare from all evaluated flooring types.

The benefits of implementing shade outweigh any possible negative impacts, and the findings from this review strongly support the implementation of shade in the feedlot setting. Access to shade allows cattle to have a choice to reduce thermal stress in a manner that does not compromise their performance or welfare. Cattle housed in an environment with shade have lower respiration rates (28, 29), and lower panting scores (30, 31) compared to their counterparts without shade. Animals provided shade were more willing to eat as shade reduced the impact of temperature highs during the middle of the day (31). Cattle with access to shade had numerous performance benefits, as well, including greater final body weights (28, 30, 31), ADG (30), DMI (28, 30, 32) and G:F (30). The sole negative impact found of shade implementation was in conflict with another study. Gaughan et al. (2010; 30) found that shaded cattle had a lower dressing percentage in contrast to Hagenmaier et al. (2016; 32) who determined cattle in an environment with shade had greater dressing percentages. Therefore, the impact of shade on dressing percentage is unclear. Overall, the listed benefits of shade outweigh the possible negative impacts, as these were limited.

Inclusion of environmental enrichment in beef cattle housing systems may be the next step to advancing cattle welfare, as well as improving the image of beef cattle production with consumers. Few studies were found that evaluated the impact of environmental enrichment on beef cattle, which is reflective of the scarcity of current literature available on the topic. However, the two studies evaluated demonstrated that environmental enrichment has either a positive or neutral impact on cattle welfare. Ninomiya and Sato (2009; 33) investigated the impact of providing feedlot steers with a log and brush and found that those steers spent a greater percentage of time eating. This finding did not correlate with an increase in performance measures. In another study, the impact of a grooming device was compared to different scent releasing (blank – no scent, lavender and milk) devices on feedlot heifers. Overall, heifers had interacted most frequently and for the longest duration of time with the rubbing device followed by the milk-scent releasing device (34). The findings of this review indicate that within a feedlot setting, environmental enrichment that allows animals to perform grooming behaviors may be most biologically appropriate as this is a behavior cattle are highly motivated to perform. Further research is needed to evaluate the long-term welfare consequences of environmental enrichment in all stages of beef cattle production.

This systematic review succeeds in investigating multiple research databases to gather the greatest amount of studies related to the topic. More notably, the author took additional approaches to review studies by examining all the articles that were cited by accepted studies, as well as articles that cited the accepted studies. The consultation between the author and a systematic review librarian was the greatest strength of this review. As the review was restricted to randomized controlled trials, there was the opportunity to assess the risk of bias for each individual study, which was viewed to be both an advantage and disadvantage. Conducting the risk of bias allowed for a more thorough analysis of these studies from a methodological standpoint, as well as assisted in determining features where beef cattle housing studies need improvement. However, this limited the review to only assessing randomized controlled trials, therefore excluding housing studies that did not fit the criteria and may have differing results that are not taken into account.

Conducting the Cochrane Risk of Bias analysis demonstrated that researchers in this field running randomized controlled trials are doing well in reporting results on all the measures obtained, as well as assessing animals on the same measures regardless of what treatment they are allocated to. However, this analysis also determined areas in which beef cattle housing randomized controlled trials could improve. A statement of random allocation of animals to treatment groups is inherent to randomized controlled trials and must be included in the communication of this research. There cannot be an assumption that readers will know that random allocation occurred. Additionally, researchers need to ensure to the reader that there is not a deviation of data in the results due to removal of animals from specific treatment groups. There is a lack of clarity in the majority of studies evaluated as to whether animals were removed or not and if animals were removed, no reference was made to how their removal impacted the study. Areas of the Cochrane Risk of Bias analysis that beef cattle housing studies did not excel in and are not likely to improve on include both allocation concealment, as well as blinding of participants and personnel. There is a consensus in that no studies reported on whether the person enrolling cattle into the treatment had knowledge of the treatment allocation. In randomized controlled trials, knowledge of treatment allocation is considered to be selection bias. However, ensuring that the person enrolling cattle in treatments does not know of which treatment the animal are entering into would be difficult due to the impossibility of blinding personnel to the treatments. In housing studies, the interventions are apparent, i.e. clear distinction between fully slatted concrete flooring and deep litter. The differences of treatments are visual and obvious. While researchers are not able to change this concept in most housing studies, there can be efforts put forth to ensure readers understand the reasoning behind a non-blinded study, as well as knowledge of allocation of treatments.

From an evaluation standpoint, there was difficulty depicting comparisons from studies as studies greatly differed in the measures that they assessed. There is not a consensus among researchers of what measures should be assessed when evaluating the impact of housing on beef cattle welfare. This is an area that requires improvement from researchers to determine how to efficiently measure the animal's response to housing. Measuring the response on similar scales will aid in future comparison of research, leading to more thorough conclusions of the impact of housing systems and their features on beef cattle welfare. Researchers should consider including an explanation for their choice of measure in future publications to assist in this effort. In addition to varying in measures, studies did not vary in the housing evaluated. The majority of studies that were found and reviewed examined the finishing feature relative to feedlot housing. Therefore, this review was restricted in its ability to cover all stages of beef production. Research that examined how housing impacts calves and cows in all stages of production was lacking. Further research is needed to conclude the impact of housing systems and features on these animals.

Beef cattle producers should understand that the housing decisions they make impact the animal's welfare, which is evident in their performance, health status and changes in their physiology and behavioral repertoire. From this review, there is evidence that consideration must be given to implementing progressive modifications to the feedlot cattle's environment, such as providing shade or environmental enrichment as these housing adaptations have positive implications on the animal's welfare state. Economics will continue to be a driving force in industry decisions; however, the results of these studies indicate that there are long-term consequences to the animal both during their lifetime, as well as the end product, as a result of their environment that they are reared in.

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# 3. THE EFFECT OF A CATTLE BRUSH ON FEEDLOT STEER PHYSIOLOGY, PERFORMANCE AND HEALTH STATUS

## 3.1. Introduction

Consumers are increasingly concerned about how agricultural animals are housed and managed. Feedlot housing is simplistically designed to maximize optimal efficiency but these motivators provide limited environmental diversity or interactive features for cattle. Animals without the opportunity to interact with their environment may experience frustration, apathy and stress; therefore increasing the diversity of stimuli animals experience and providing them control over their environment has been documented to enhance their welfare through expression of highly motivated behaviors (Pelley et al., 2005; Kohari et al., 2007). The implementation of environmental enrichment (EE) is described as the effort to improve biological functioning or the quality of life for an animal by providing environmental stimuli that promotes the performance of species appropriate behaviors (Newberry, 1995; Fraser, et al., 1997; Reinhardt and Reinhardt, 2003).

Implementation of EE devices into the feedlot may create an environment that is less stressful for cattle that may be beneficial from a performance (e.g. efficiency, carcass quality, health) standpoint. Studies in other livestock species (e.g. swine) indicate a potential for enhanced performance (e.g. increased weight gain, lower feed conversion rate) with implementation of EE (McGlone and Curtis, 1985; Waran and Broom, 1993; Krötzl et al.,1994; Rodarte et al., 2004). Cattle are biologically motivated to perform an extensive range of grooming behaviors, however, feedlot cattle are limited in their ability to express specific grooming patterns (e.g. grooming with an inanimate object; Wilson et al., 2002) therefore EE designed to promote this type of behavior has potential to be beneficial to feedlot cattle welfare. The objective of the current study was to quantify the impact of EE in the form of a cattle brush on the physiology, performance and health status of feedlot cattle. Cattle with access to EE were expected to have lower hair cortisol concentrations, increased productivity and lower morbidity rates than cattle without access to EE.

### 3.2. Materials and Methods

All procedures were approved by the West Texas A&M – Cooperative Research, Education and Extension Team University Animal Care and Use Committee (approval number 01-09-17). The experimental period lasted a total of 253 days from November 2017 to July 2018 with the day of brush implementation serving as d 0. Cattle arrived at the feedlot on d -55 and were slaughtered on d 161 and d 198, respective to their weight block.

#### 3.2.1. Animals and Housing

Fifty-four predominately British and British-Continental crossbred steers were shipped to the Texas A&M AgriLife Research Feedlot in Bushland, Texas in November 2017. Cattle were assigned to groups according to initial live body weight and allocated to one of six identical pens. Each pen was 25.5 x 7 m (19.83m$^2$ per animal) with earthen flooring. Shade was provided in the form of a partial roof covering (5 x 7 m; 5m$^2$ per animal). Each pen provided nine individual Calan head gate feeders and housed nine animals accordingly. Water was provided *ad libitum* from an automatic water trough.

Upon arrival, each steer was fitted with a unique ear tag for individual identification. Calves were adapted to the Calan gate system for 52 d prior to study commencement. One steer was removed from the study prior to study commencement, as he did not adapt to the Calan gate system. Two more steers were removed for the same reason after the study commenced resulting in 51 steers in total being utilized in the study.

### 3.2.2. Diet

Cattle were randomly assigned to steam-flaked corn based finishing diets on a dry matter basis with 5%, 10% or 15% corn stalk inclusion. All three diets were equally distributed throughout pens. See Table 3.1 for dietary ingredients and nutritional content.

### 3.2.3. Treatments

Steers were blocked by body weight into a light (283.95 ± 13.75 kg) and heavy block (320.69 ± 12.97 kg). Pens were randomly assigned to one of two treatments (3 pens per treatment with 9 animals per pen):

1) Environmental enrichment (**BRUSH**, a cattle brush secured to the fence line; 25 animals) or

2) Control (**CON**, no brush; 26 animals)

In each of the BRUSH pens, a single brush was welded to the fence line furthest from the feed bunk. Each brush consisted of 12 brush heads implemented in an "L" shaped fashion onto wooden boards (Fig. 3.1). Brushes were removed from all treatment pens on d 129 relative to brush implementation due to issues with attachment.

### 3.2.4. Physiological Measurements

Hair shedding scores were collected from cattle upon their arrival at the feedlot (d -55) and at d 161 relative to brush implementation. One trained observer assigned each steer a hair shedding score (Table 3.2; Gray, et al., 2011). Individual body weights were measured at 35 d intervals throughout the study for a total of six weights. Hair samples were collected at each weighing by cutting hair from the tail switch with scissors as close to the skin as possible (Moya et al., 2013). Hair samples were collected 35 d after initial live body weight collection therefore resulting in a total of five hair samples per animal across the duration of the trial.

### 3.2.5. Cortisol Analysis

Hair samples were stored in a -80º C freezer until analysis. Cortisol was extracted from hair based on the methodology developed by Moya et al. (2013). Hair was washed in warm water then allowed to dry overnight. Samples were then washed twice in isopropanol and dried for 5 d at room temperature. Hair was minced as finely as possible using the ball mill method of grinding. Methanol was added to samples (1mL/20 mg). Samples were placed in a sonicator for 30 minutes prior to incubation, which occurred for 16-18 hours. Supernatant was pipetted off into a 2 mL microcentrifuge tube. Tubes were inserted into a block heater set at 45º C for approximately 10 h. Samples were reconstituted with 100 µL of phosphate buffered saline before being vortexed. Hair samples were then analyzed for cortisol using Salimetric's High Sensitivity EIA I-3002 kit (Salimetrics Expanded Range, High Sensitivity 1-E3002, State College, PA). The intra- and inter- assay CV's were 5.18% and 4.00%, respectively.

### 3.2.6. Production Measurements

Average daily gain (**ADG**) as well as gain:feed (**G:F**) ratio were calculated as an average for each individual steer based on intake. Dry matter intake was also calculated. Cattle were slaughtered at Tyson Foods in Amarillo, Texas. Upon slaughter, carcasses were evaluated for adjusted ADG and adjusted G:F. The following carcass data were collected: hot carcass weight (**HCW**), dressing percentage, adjusted fat thickness, rib eye area **(REA)**, marbling score, kidney, pelvic and heart fat **(KPH)** percentage, quality grade and liver lesion score.

### 3.2.7. Health Measurements

Trained animal husbandry technicians conducted daily health monitoring checks and maintained treatment, retreatment and mortality records. The percentage of the pen treated, as well as, the cost of treatment per pen was calculated. Cattle requiring medical intervention were treated according to the consulting veterinarian's recommendation.

### 3.2.8. Statistical Analysis

For all physiological and performance data, response data consisted of the individual animal serving as the experimental unit. Averages of treatment means were calculated for all performance data. On a treatment basis, performance was evaluated utilizing a linear mixed model (PROC MIXED, SAS v9.4, SAS Institute, Cary, NC) with the exception of liver abscesses that were evaluated with the PROC GLIMMIX model. For initial body weight, final body weight, DMI, ADG, G:F, carcass ADG, carcass G:F, HCW, dressing percentage, adjusted fat thickness, REA, marbling score, KP percentage, liver abscess scores, cortisol and hairs scores, animal ID within pen by treatment by diet and block were the random effects used to correctly specify error terms. Diet and EE treatment were the fixed effects used. Differences were considered significant at $P < 0.05$ and effects within $0.05 < P < 0.10$ were considered meaningful tendencies.

## 3.3. Results and Discussion

Treatment did not significantly impact physiological or performance metrics ($P > 0.05$). Research day impacted hair shedding scores ($P < 0.001$). Health measures could not be analyzed, as cattle did not require medical intervention throughout the duration of the trial.

### 3.3.1. Physiological

Hair shedding scores were not impacted by treatment ($P > 0.05$). As this study was conducted in the Southern region of the United States, the authors were interested in how the cattle brush would impact hair shedding scores as coat thickness can have implications for heat stress. Cattle that do not properly shed their coats seasonally are subject to greater heat stress response (e.g. reduced mobility, appetite, health) in comparison to cattle that do obtain their slick coats in a timely manner (Gray et al., 2011). Furthermore, cattle that endure heat stress have reduced performance, as well as suffer from an animal welfare standpoint. While several factors contribute to heat stress, producers may look towards environmental interventions to provide cattle options to cope with weather conditions such as shade. Simroth et al. (2017) collected survey data from feedlot producers in the High Plains region of the United States. Of 43 feedlot respondents, only 7 had shade implemented in their finishing pens indicating that producers may not perceive shade to be a viable option for their operation and an alternative housing feature that mitigates heat stress may be appealing to this group of producers. However, the results of this study indicate that a cattle brush would not be a suitable intervention for heat stress with the current information but additional research is needed to determine if an impact of EE intervention could be identified by conducting hair scoring at a greater frequency.

Hair shedding scores ($P < 0.001$) decreased over time with scores being greater upon arrival at the feedlot compared to at the completion of the trial (Fig. 3.2). As the final hair scoring occurred in June, these results follow a similar pattern as previously reported studies on hair shed scores (Gray et al., 2011; Foster et al., 2016). However, cows that shed their coats in May had greater performance (e.g. body weights at weaning, body weights pre-weaning, calf-adjusted birth weight) compared to cows that experienced their coat shedding in June and July (Foster et al., 2016). A limitation of the present study was the inability to score coats on a greater frequency as this may have provided insight into the rate of hair shedding based upon the presence or absence of a brush, as well as help to determine if there would be any performance benefits.

Hair cortisol concentration was not impacted by treatment, research day or their interaction (*P* > 0.05; Fig. 3.3). This did not support our hypothesis that the cattle brush would decrease the activation of the hypothalamic-pituitary-adrenocortical (HPA) system in feedlot cattle. Evaluation of distress in beef cattle is determined through changes in activity of the HPA system of the animal, particularly through examining levels of cortisol production (Moya et al., 2013). Grooming is a behavior in dairy cattle that has been linked to stress with the suggestion that increased levels of self-grooming may be the animal's way of reducing stress levels (Krohn, 1994). Cattle that receive grooming from another animal have demonstrated physiological indications of calming effects through a reduction in heart rate post-grooming (Laister et al., 2011). A study conducted by Chen et al. (2017), beef cows were brushed by hand for 3 minutes a day as a form of EE and had blood samples collected at -6, 0, 3, 15 and 30 minutes relative to brushing. There was no impact of EE on cortisol concentration; however, changes in oxytocin concentrations were significantly different in cows that received brushing compared to ones that did not demonstrating cattle comfort. Additionally, there have been suggestions that cattle have a behavioral need to self-groom and therefore allowing cattle to express this behavior fully through implementation of a brush could reduce stress levels (Ewing et al., 1999; DeVries et al., 2006).

As EE is implemented to promote performance of species-specific behaviors through increasing environmental complexity and to reduce frustration and negative stress experienced by the animal, there could be an expectation of a reduction in cortisol production. However, previous studies that evaluated the impact on EE in livestock, laboratory and zoological animals did not find results supportive of this claim (Liu et al., 2006; Moncek et al., 2014; Cornale et al., 2015; Chen et al., 2017; Backus and McGlone, 2018). To the author's knowledge, these previous studies measured blood or fecal cortisol and the current study is the first to examine the relationship between EE and hair cortisol. Hair cortisol is an indicator of long-term HPA activity over time (e.g. weeks to months), which may be more applicable to EE studies (Meyer and Novak, 2012). As the cattle brush was implemented into the feedlot, collecting hair samples was advantageous since this method of examining cortisol has been identified to depict chronic stress in cattle (Burnett et al., 2014; Marti et al., 2015; Moya et al., 2015). Cortisol concentrations in hair demonstrate an average concentration of the hormone not impacted by diurnal rhythms or acute stressors (Burnard et al., 2017) and not subject to confoundment due to handling as this collection method is considered non-invasive (Otovic and Hutchinson, 2015).

Hair cortisol results did not indicate that the cattle brush was successful in reducing cortisol concentrations in feedlot cattle as hypothesized, yet the elevation of cortisol in cattle provided the brush may be indicative of eustress rather than distress. Across species, EE has been considered to be an intervention that benefits animal welfare in a positive manner by increasing species appropriate behavior and reducing abnormal and stereotypical behavior, however, these devices have not shown an impact on HPA axis activation (Otovic and Hutchinson, 2015). A review conducted by Otovic and Hutchinson (2015) indicated that a collection of multiple stress matrices is needed to indicate a complete picture of animal welfare. In the present study, behavioral indicators did show a reduction in boredom and aggression over time with cattle provided the brushes engaging in headbutting and bar licking less frequently than cattle not provided EE. Ultimately, as there is no previous literature examining the relationship between hair cortisol and EE in feedlot steers to compare these results to, more research is needed to fully elucidate this relationship.

**3.3.2. Production**

Steer performance and carcass data are presented in Table 3.3. Treatment did not impact ADG, DMI and F:G ($P > 0.05$). Similarly, there was no impact ($P > 0.05$) of treatment on carcass adjusted ADG and carcass adjusted G:F. All carcass measurements including HCW, dressing percentage, adjusted fat thickness, REA, marbling score, quality grades and liver abscesses were not impacted by treatment ($P > 0.05$). BRUSH cattle tended to have lower KPH percentages compared to CON cattle ($P = 0.08$), however, this finding provides limited evidence of a performance benefit as REA, HCW and fat thickness were not impacted by EE.

To the authors' knowledge, this is the second study evaluating the impact of EE on feedlot cattle performance. Ishiwata and colleagues (2006) examined the impact of EE similar to a cattle brush (i.e. either a spent oil drum can containing hay or a spent oil drum can containing hay wrapped in artificial turf) on the following performance traits: body weight, ADG, carcass weight, REA, beef belly thickness, subcutaneous fat thickness between the $6^{th}$ and $7^{th}$ rib, marbling score and yield ratio. In congruence with the present study, EE did not impact body weight, ADG, dressed carcass weight or marbling score ($P > 0.05$). However, the results of the Ishiwata et al. (2006) study indicated that steers with access to EE had thicker beef bellies compared to those without ($P < 0.01$). This is not a measure that was evaluated in the present study, however, may be encompassed in the adjusted fat thickness as BRUSH cattle had greater fat thickness compared to CON cattle although not significant. Furthermore, measurement of beef belly thickness may be more relevant to operations that aim to service a market that prefers a fattier product (e.g. brisket) and therefore producers that fit this niche may be further encouraged to implement EE in the form of a cattle brush. However, as there is still limited literature on the influence of EE on beef cattle performance, further comparisons are not possible at the present time. The results of the current study do indicate that the presence of EE in feedlot pens does not negatively impact performance metrics.

**3.3.3. Health**

Cattle did not require veterinarian intervention at any point. No cattle were treated throughout the duration of the study and therefore, there were no reports as to percentage of pen treated or cost of treatment per pen. No cattle were euthanized or removed from trial due to health reasons. As there was no data for health analysis, there are no results to report. Brush usage is considered a low-resilience behavior as despite the motivation to use the brush, cattle will cease to perform this behavior during times when energy resources are limited (e.g. sickness, injury; Mandel et al., 2018). Therefore, researchers have been interested in the potential of tracking brush usage to determine health variations in dairy cattle (Newby et al., 2013; Toaff-Rosenstein et al., 2017; Mandel et al., 2017; 2018). Newby and colleagues (2013) examined the impact of providing a cattle brush to Holstein cows during parturition with the intent of evaluating the effects of dystocia, however, there were not enough cows with dystocia to determine any relationship. A study conducted by Mandel and colleagues (2017) indicated that Holstein dairy cows diagnosed with metritis differed in brush usage of a brush placed furthest from the feed bunk compared to their healthy conspecifics during the week of diagnosis and during the first and second week of being treated. Similar results were found with lameness detection of dairy cattle through brush usage (Mandel et al., 2018). The present study is the first attempt to examine the relationship between health and brush usage in the feedlot. As all cattle remained healthy and no euthanasia was required, there is not a clear consensus as to if monitoring brush usage in the feedlot has potential to be an early indicator of disease or injury in the feedlot. Future studies are needed to conclude the correlation between brush usage and health with beef cattle.

**3.4. Conclusion**

The current study aimed to evaluate the implementation of a cattle brush in feedlot pens on steer physiology, performance and health. The brush did not reduce cortisol concentrations or enhance performance metrics and comparisons on morbidity could not be conducted. Ultimately, the cattle brush did not negatively impact stress physiology or performance of feedlot steers. This lack of detrimental impact illustrates that implementation of a cattle brush is not a risky management strategy to implement and would provide complexity in the feedlot environment. As consumers are demanding that agricultural animals be provided with opportunities to perform natural behaviors, producers can choose to implement this husbandry strategy with the knowledge that the presence and use of a cattle brush will promote cattle welfare without compromising productivity.

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# 4. IMPACT OF A CATTLE BRUSH ON THE BEHAVIOR OF FEEDLOT STEERS

## 4.1. Introduction

Feedlots are a sector of the beef industry where cattle are housed during the fattening stage of production. This housing system is designed to promote weight gain and efficiency in a reduced amount of space; as a consequence, this housing environment inhibits the performance of some of the animal's natural behavioral patterns as this environment provides limited complexity. While feedlot environments meet the basic physiological needs of cattle, they lack specific environmental stimuli (e.g. trees, hills, forage) that cattle would experience and interact with while housed on range or pasture.

Animals housed in environments that lack mental stimulation might become bored, which can impair both animal welfare and producer profitability. As feedlot cattle are able to acquire their required nutrients in less time compared to their counterparts reared on pasture who engage in additional grazing and foraging behaviors, feedlot cattle have more time available to idle which may contribute to boredom (Pelley et al., 1995). Boredom can lead to the development of stereotypic behaviors that are performed in an effort to cope with the frustration of unfulfilled behavioral needs (Wood-Gush et al., 1983; Mason and Latham, 2004) or animals engaging in behaviors (e.g. aggression, bulling, digging, dirt eating, bar licking) that can be dangerous to themselves, their conspecifics or their environment. Cattle performing abnormal, stereotypic or agonistic behaviors demonstrate lower weight gains and consequently, lower profit for beef producers (Pelley et al., 1995). Implementation of biologically appropriate and species specific environmental enrichment (EE) has the potential to enhance feedlot cattle welfare and productivity by mitigating boredom, decreasing aggression and promoting the performance of diverse and appropriately distributed species-specific behaviors.

Providing EE to captive animals has improved the welfare for zoo and laboratory animals, as well as various livestock species. In the zoological field, EE is a standard component of animal husbandry that is provided not only as a response to animal welfare concerns but also to improve the educational experience of zoos. Zoo EE programs were designed to promote natural behavioral patterns that mimicked those experienced in the wild (Chamove, 1989). A meta-analysis of 54 studies investigating EE in mammalian zoo animals concluded that providing EE reduced the performance of stereotypic behaviors by captive animals and therefore improved animal welfare (Shyne, 2006). EE may not only improve the welfare of laboratory animals used as human models (e.g. rodents) by reducing abnormal or stereotypic behaviors (e.g. barbering, bar biting), but also impacts cognitive functioning and brain development as enriched animals displayed different responses in their brain (e.g. increased dendritic branching, increased cell size, improvements to learning and memory; Mohammad et al., 2002; Petrosini et al., 2009; Sale et al., 2009). In livestock species, EE has been demonstrated as effective through providing the animal the opportunity to engage in behaviors in which they are motivated to perform and would not be able to perform without EE (e.g. providing perches and/or nesting boxes to laying hens to perform pre-egg laying behaviors; maintaining pigs in an environment with access to substrate for rooting;

Ninomiya, 2014).

Cattle are internally motivated to perform a range of grooming behaviors. Yet, while maintained in a feedlot, cattle are limited in their opportunities to engage in the full range of these grooming behaviors (Wilson et al., 2002). When ranging extensively, cattle will use natural trees to engage in grooming (Simonsen, 1979; Frazer and Broom, 1990). Cattle are unable to use self-grooming or allogrooming as replacement behaviors to grooming with an inanimate object as the motivation behind this behavior differs from allogrooming and self-grooming (Kohari et al., 2007). Therefore, EE designed to promote this type of grooming behavior may be beneficial for feedlot cattle. Feedlot cattle preferred a brush over a scent-releasing device (Wilson et al., 2002) and additional evidence of brush use in dairy cattle (DeVries et al., 2007; Newby et al., 2013) suggests that brushes are a suitable form of EE for cattle.

In the present study, cattle were provided with static brushes as EE. The objective was to investigate the impact of a cattle brush on feedlot steer behavior. We hypothesized that when cattle have access to a brush, they will perform stereotypies (e.g. bar licking, tongue rolling) and agonistic behaviors (e.g. headbutting, kicking and mounting) less frequently and for a shorter duration of time. Maintenance and social behaviors will be quantified to determine if there are any differences in the frequency and duration of their performance between cattle exposed to environmental enrichment and those without access to the cattle brush.

## 4.2. Materials and Methods

All procedures were approved by the West Texas A&M – Cooperative Research, Education and Extension Team University Animal Care and Use Committee (approval number 01-09-17). The experimental period lasted a total of 253 days from November 2017 to July 2018 with the day of brush implementation serving as d 0. Cattle arrived at the feedlot on d -55 and were slaughtered on d 161 and d 198, respective to their weight block.

### 4.2.1. Animals and Housing

Fifty-four predominately British and British-Continental crossbred steers were shipped to the Texas A&M AgriLife Research Feedlot in Bushland, Texas, United States in the fall of 2017. Cattle were assigned to groups according to initial live body weight and allocated to one of six identical pens. Each pen was 25.5 x 7 m (19.83$m^2$ per head) with earthen flooring. Shade was provided in the form of a partial roof covering (5 x 7 m; 5$m^2$ per head). Each pen provided nine individual Calan head gate feeders and housed nine animals accordingly. Water was provided *ad libitum* from an automatic water trough.

Upon arrival, each steer was fitted with a unique ear tag for individual identification. Calves were adapted to the Calan gate system for 52 days prior to study commencement. One steer was removed from the study prior to study commencement, as he did not adapt to the Calan gate system. Two more steers were removed for the same reason after the study commenced resulting in 51 steers in total being utilized in the study.

#### 4.2.2. Diet

Cattle were randomly assigned to steam-flaked corn based finishing diets on a dry matter basis with 5%, 10% or 15% corn stalk inclusion. See Table 3.1 for dietary ingredients and nutritional content.

#### 4.2.3. Treatments

Steers were blocked by body weight into a light (283.95+/- 13.75 kilograms) and heavy block (320.69+/- 12.97 kilograms). Pens were randomly assigned to one of two treatments (3 pens per treatment):

1) Environmental enrichment (**BRUSH**, a cattle brush was secured to the fence line) or
2) Control (**CON**, no brush)

In each of the BRUSH pens, a single brush was attached to the fence line furthest from the feed bunk. Each brush consisted of 12 brush heads secured to wooden boards in an "L" shape and were welded to the pen fence line.

#### 4.2.4. Behavioral Observations

Cattle behavior in the pen was recorded from 08:00 to 17:30 on d -2, -1, 0, 1, 2, 4, 8, 16, 32 and 64 relative to treatment implementation using a closed circuit video camera recording system. Cameras were installed to ensure no blind spots within the pen.

Behavioral data was decoded from video recordings using instantaneous scan samples and continuous sampling methods (Altman, 1974; Mitlöhner et al., 2001). Instantaneous scan sampling at 10-minute intervals were conducted by three trained observers using the VLC Media Player (Version 3.0.1, VideoLan, France). For each scan sample, the number of steers within each pen lying, eating and drinking was recorded (Table 4.1). Continuous sampling recorded the frequency and duration each steer spent engaged in allogrooming, bar licking, tongue rolling and utilizing the brush, as well as the frequency of headbutting, kicking and mounting (Table 4.1). All continuous behavioral data was collected by twenty-three trained observers utilizing BORIS (Version 6.1.4) (Friard and Gamba, 2016). Inter-observer reliability between observers and trainer, as well as among observers, was no less than 95% accuracy.

To measure rumination behavior and animal activity, individual steers were fitted with SCR rumination collars (HR Tag; SCR Dairy, Netanya, Israel) that utilize accelerometers to record rumination and activity duration for the same behavioral schedule as the video recordings.

**4.2.5. Statistical Analysis**

For all response data, pen served as the experimental unit. Total number of headbutts, tongue rolling, bar licking and brush use frequencies and durations were averaged for each animal within pen for each day. These averages were square root transformed for normality and homogeneity of error variance. Total number of rumination and activity durations were averaged for each animal within pen. These averages were not square root transformed as the data was normally distributed. Instantaneous scan samples were combined within pen to calculate daily mean proportions of calves performing lying, drinking and feeding then pooled within day. Instantaneous means were converted to proportions of each pen and these proportions were arcsin square root transformed to achieve normality and homogeneity of error variance.

On a pen basis, transformed behaviors, as well as rumination and activity, were evaluated as repeated measures using a linear mixed model (The Mixed Procedure, SAS v9.4, SAS Institute, Cary, NC). Pen nested within day by diet treatment by EE treatment interactions, as well as individual animal nested within research day, EE treatment and diet treatment interactions were random effects used to correctly specify error terms. Fixed effects were EE treatment and diet. Means were separated among interactions or levels of fixed effects using paired t-tests when the fixed effect was significant. Differences were considered statistically significant at $P < 0.05$ and effects within $0.05 < P < 0.10$ were considered meaningful tendencies.

**4.3. Results**

Behavioral data are presented in Table 4.2. An interaction between EE treatment and research day was observed for the frequency ($P = 0.009$) and duration ($P = 0.035$) of bar licking. Cattle housed in CON pens performed bar licking more frequently and engaged in longer bouts of bar licking on d 0, 1 and 16 (Figure 4.1). The frequency of headbutting was impacted by the EE treatment x research day interaction ($P = 0.006$). Cattle housed in BRUSH pens performed fewer headbutts than cattle housed in CON pens on d -1, 2, 4 and 16 (Figure 4.1). An interaction between EE treatment and research day was observed for the duration of activity ($P < 0.0001$) with cattle housed in CON pens engaging in more activity than cattle housed in BRUSH pens on d -2 and -1 (Figure 4.1). For BRUSH pens only, the frequency and duration of brush usage changed over time (*P* < 0.0001). Steers interacted with the brush more often and for a longer duration of time on d 0 compared to all other research days (Figure 4.2).

The interaction between EE treatment x research day tended to impact allogrooming frequency (*P* = 0.0523); however, this was not observed for allogrooming duration (*P* > 0.10). Cattle housed in CON pens engaged in allogrooming more frequently on d 0, 2 and 16 compared to cattle housed in BRUSH pens (*P* < 0.05; Figure 4.1). Allogrooming duration increased over time (*P* < 0.0001) with the shortest durations occurring on d -2, -1 and 2 and the longest duration occurring on d 32 (Figure 4.3). Kicking frequency was not impacted by treatment, research day, diet or their interaction (*P* > 0.05). Mounting frequency was not affected by treatment but decreased over time (*P* = 0.013) with the greatest number of mounts performed on d 8 (Figure 4.3). Tongue rolling frequency and duration change over time (*P* < 0.0001). Cattle performed more tongue rolling bouts and spent more time tongue rolling as the study progressed (Figure 3). Rumination duration decreased over time (*P* < 0.0001) with the exception of an increase on d 64. Treatment did not impact the proportion of the pen lying, eating or drinking (*P* > 0.05). The proportion of steers lying (*P* = 0.001; Figure 4.4) changed over time with steers lying the least on d 0 and 4.

Several behaviors were influenced by the interaction between diet and EE. Cattle in BRUSH pens that consumed the diet with 5% corn stalk inclusion engaged in allogrooming less often (*P* = 0.006) and for a shorter duration of time (*P* = 0.008) than cattle in CON pens (Figure 4.5). The interaction between EE treatment and diet impacted the frequency (*P* = 0.001) and duration (*P* = 0.0004) of tongue rolling. Cattle housed in

BRUSH pens and were consuming a diet of 15% corn stalk inclusion engaged in more tongue rolling bouts for a longer duration of time (Figure 4.5). A similar trend was observed for the duration of time spent ruminating ($P$ = 0.064). Cattle in BRUSH pens that consumed the 15% corn stalk inclusion diet spent a longer duration of time ruminating compared to cattle housed in CON pens (Figure 4.5).

**4.4. Discussion**

In the current study, EE reduced aggression and the performance of stereotypic behaviors. Further, cattle demonstrated a sustained interest in EE, suggesting that this form of EE (a cattle brush) provided long-term mental and physical stimulation. Cattle in the BRUSH pens performed fewer headbutts and engaged in bar licking less often and for a shorter duration of time. These findings correspond with results from Ishiwata et al. (2006) where cattle exposed to EE (i.e. a spent drum can that held straw and was fitted with artificial turf) spent less time bar licking in comparison to cattle without access to EE. Cattle exposed to the spent oil drum can were more active (e.g. eating, drinking, grooming, investigating, salt licking and agonistic behaviors) after enrichment installation. Similarly, feedlot cattle exposed to a brush performed fewer aggressive behaviors compared to cattle exposed to other EE types (i.e. salt block, straw bale; Pelley et al., 1995). Cattle in the BRUSH pens had the opportunity to engage in grooming and scratching behaviors. By having access to EE, cattle in the BRUSH pens may have redirected their energy away from performing aggressive and stereotypic behaviors to spend their energy engaging in beneficial brush directed behaviors.

In the current study, steers in the BRUSH pens interacted with the brush most frequently and for the longest duration of time on d 0. Their interest in the brush was sustained over time as the frequency and duration of brush usage remained relatively stable throughout the study. This corresponds with previous findings. Wilson et al. (2002) demonstrated that frequency and duration of brush usage decreased after Day 2 relative to brush implementation, ($P < 0.05$), however, feedlot cattle did not habituate to the brush but maintained interest in the EE through the duration of the study. The first study that examined brush usage in cattle, indicated that 79% of 48 mid-lactation dairy cows interacted with a mechanical brush on the day of installation and that within one week of having access to the brush, all animals had used the brush (Georg and Totscek, 2001). However, DeVries et al. (2007) found that 57% of 72 mid-lactation dairy cows interacted with a mechanical brush within 24 hours of installation and that every animal with the exception of one used the brush by the end of the trial period. In comparison, 96% of steers housed in BRUSH pens in the present study interacted with the brush on Day 0 and all animals had used the brush by Day 1. This suggests that a brush is an EE device that feedlot cattle find attractive and maintain interest in over time.

Furthermore, duration of brush use can be influenced by context. Mid-lactation dairy cattle engaged in brush usage for five to seven minutes per day (DeVries et al., 2007) whereas dairy cows provided a mechanical brush prior to calving engaged in brush usage for approximately 31 minutes per day within the 72 to 48 hours prior to giving birth (Newby et al., 2013). In the present study, steers used the brush for an average daily duration of ten to eleven minutes. This information can provide context to researchers and stockpersons managing feedlot cattle that are provided a cattle brush as to expectations of normal brush usage patterns. As brush usage is considered a low resilience behavior, there has been evidence that dairy cattle diagnosed with illnesses (e.g. metritis, lameness) differ in brush usage when the brush is placed furthest from the feed bunk compared to healthy conspecifics (Mandel et al., 2017; 2018). This suggests that individual animal brush use patterns may be useful in the feedlot in identifying sick or injured animals.

Steers housed in CON pens engaged in allogrooming more frequently compared to those housed in BRUSH pens, however, there were no differences in duration of allogrooming between treatments. This finding is only in partial agreement with a study that examined the impact of trees provided as EE for pastured beef cattle in which no differences in the frequency or duration of allogrooming performed was observed between cattle that had access to EE and those that did not. Pastured cattle engaged in grooming with a tree at the same frequency that cattle engaged in allogrooming suggesting that there is a separate motivation to groom with an inanimate object rather than that the animal uses the object to reach a body spot that they are incapable of reaching on their own (Kohari et al., 2007). The present results partially support this suggestion, as exposure to a cattle brush did not impact allogrooming duration, however, allogrooming duration did increase over time and peaked one-month post study-commencement. Allogrooming has been proposed to be important in the social development of cattle as this behavior may have hygiene, tension reducing and bonding effects, as well as serve a role in the formation and maintenance of social bonds in cattle herds (Sato et al., 1993). Šárová et al. (2016) observed a herd of 15 beef cows between three and ten years of age to determine the role of dominance on allogrooming behavior concluding that high-ranking animals both engaged and received allogrooming, allogrooming behaviors were directed down the social hierarchy and that allogrooming is an important behavior in the social network of the herd. Although the present study did not establish social rankings of cattle, the results do suggest that social dynamics in feedlot cattle become established after two months in the home pen and are maintained over time. Further, the difference in frequency of allogrooming observed may indicate that steers housed in the BRUSH pen did not need to perform allogrooming for conspecifics as often due to the availability of an inanimate object to groom with, however, when they did engage in allogrooming behavior the duration was not impacted by treatment due to the social relevance of this behavior.

Although cattle in the BRUSH pens did not differ in the frequency that they engaged in mounting compared to cattle in the CON pens, cattle did perform fewer mounting events over time maintained in the feedlot. Mounting peaked on d 8 relative to brush implementation, which was during the second month spent in the feedlot. Cattle have been known to use aggressive behaviors to establish a hierarchy and the intensity of the performance of these behaviors may be magnified upon entry to the feedlot, as this is an artificial and socially stressful environment (Hafez and Bouissou, 1975; Ulbrich, 1985). The present study results correspond with previous literature that has observed an increase in mounting behavior in pens of newly introduced cattle suggesting that this behavior is involved in the development of the social hierarchy (Irwin et al., 1979;

Klemm et al., 1983). Therefore, the results suggest that animals should be monitored for riding during the initial entry into the feedlot or for the first two months animals are maintained in a new home pen as the social dynamic is established.

Tongue rolling was not impacted by EE yet increased in frequency and duration over time. Tongue rolling has primarily been considered a stereotypical behavior in cattle (Ishiwata et al., 2008). The increase in tongue rolling over time spent in the feedlot may be indicative of increased frustration. Multiple hypotheses have been proposed regarding the motivation behind tongue rolling in cattle including diet (e.g. restrictive allowances of roughage, high levels of concentrate; Redbo et al., 1996; Redbo and Nordblad, 1997), gastrointestinal discomfort (Bergeron et al., 2006), prior experiences (e.g. artificial suckling; Sato et al., 1994), or a consequence of the environment (e.g. barren, lacks complexity, restrictive in nature; Seo et al., 1998). Bar licking was reduced by the presence of the cattle brush but tongue rolling was not. This suggests that these two oral stereotypies might be operated by different mechanisms and consequently have differing motivations. The results of this study are congruent with previous EE research that indicated tongue rolling was not influenced by provision of EE in the form of a spent oil drum can holding hay (with or without artificial turf attached; Ishiwata et al., 2008). This supports the conclusion that a grooming device may not be an appropriate type of EE to reduce tongue rolling behaviors.

No differences between treatments were observed for lying, eating drinking or ruminating. The treatment x research day interaction observed for activity was not relevant to the brush treatment as these differences were observed for d -2 and -1 prior to brush implementation. However, length of time in the feedlot did influence the proportion of the pen lying. As pen riders have been anecdotally known to observe cattle behavior as "normal" when 1/3 of the pen is lying, 1/3 of the pen is at the feed bunk and the remaining 1/3 is engaged in other types of behaviors, this difference is of importance to note for animal caretakers' consideration when monitoring cattle. Stockpeople should expect cattle to spend less time lying during the first two months at the feedlot as the cattle become familiar with new surroundings and establish new social hierarchies. Similarly, cattle reduced the time spent ruminating over the duration of time spent in the feedlot. The rumination data collected in this study were captured during the video recording hours only, which may explain the reduction in rumination observed over time as cattle will ruminate during the day if there are no interruptions (e.g. feeding, weights, health checks), however, most rumination occurs at night when cows are at rest (Grant et al., 1990; Dado and Allen, 1994; Paudyal et al., 2016). This rumination pattern may also be beneficial for caretakers to acknowledge. Previous literature in dairy has suggested that using technology, such as sensors, to monitor rumination in real time may assist in early detection of disease and ruminal acidosis risk as cattle tend to ruminate less when ill (Beauchemin, 2017). As the cattle in the present study remained healthy throughout the duration of the trial, no clear conclusions can be made about this relationship, however, caretakers should consider that rumination durations during the day decrease over time in the feedlot and factor this into their decision-making.

To the authors' knowledge, previous research has not investigated the interaction between a grooming device as a form of EE and diets with differing corn stalk inclusion levels. Cattle housed within BRUSH pens and having a 5% corn stalk inclusion diet had a reduction in allogrooming behavior both in frequency and duration while cattle housed within BRUSH pens and having a 15% corn stalk inclusion diet had an increase in tongue rolling frequency and duration, as well as rumination duration. For rumination, previous research by Gentry et al. (2016) indicated a similar pattern of behavior with feedlot steers provided a 10% corn stalk inclusion diet ruminating for a longer duration compared to those fed a 5% corn stalk inclusion diet suggesting that increased particle size increases rumination. This would explain the diet portion of the interaction, however, does not offer insight into the role of the brush in this relationship. The present results demonstrate that while allogrooming, tongue rolling and rumination are all oral behaviors, they may not have the same motivation, and therefore there may be a connection between motivation of behavior, presence of EE and corn stalk inclusion rate. The theory that rumination time increases salivary flow to the rumen (Gentry et al., 2016) has potential to explain why tongue rolling duration and frequency also increases for cattle provided a brush that are consuming a diet of 15% corn stalk inclusion. However, with the information given and lack of previous literature pertaining to EE and these behaviors and diets, we cannot make that conclusion at this time.

## 4.5. Conclusion

Feedlot environments require cattle to change their time budgets from when they were housed on pasture. Therefore, EE designed to promote the performance of behaviors that they do not have the opportunity to perform in the feedlot environment but are motivated to do so, can enhance cattle welfare and alleviate potential boredom. Feedlot housed cattle with access to brushes performed fewer stereotypies and aggressive behaviors. These results suggest that brush implementation may not only be beneficial in feedlot pens but also could be advantageous in reducing aggression in other stages of production where cattle experience similar changes (e.g. receiving pens, auction barns). As consumers may view EE in the beef feedlot industry positively, this could be an added benefit of incorporating brushes into housing facilities. Future research should further investigate the optimal ratio of animals to brush, the usefulness of a brush in detecting sick animals and the impact of a brush on bulling rates. Ultimately, this study demonstrated that feedlot steers housed in BRUSH pens had improved welfare as reflected by a reduction in stereotypic and aggressive behaviors, as well as continual interest in the brush over the duration of the study. Therefore, brushes may be a viable option for EE in the feedlot environment.

## 4.6. Literature Cited

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# 5. CONCLUSIONS

Beef cattle welfare is influenced by the environment. As cattle are maintained in different housing systems for various portions of their lives to ultimately become a food product for consumers, cattle producers have a responsibility to consider the consequences of their housing decisions on the animal's productivity, physiology, performance and behavior. During the fattening stage in particular, cattle housed in feedlots do not have the opportunity to express behaviors similar to when they were housed on pasture. This inability to perform these behaviors can result in boredom that can lead to displays of agonistic and stereotypic behaviors.

The provision of EE, in the form of a cattle brush, is a promising solution to this issue because cattle that had access to a brush showed a reduction in headbutting and bar licking behaviors, further the cattle maintained interest in the brush throughout the duration of the study. The cattle brush did not negatively impact cattle performance or physiology demonstrating that this is not a risky management strategy to implement. In conclusion, producers should strongly consider a cattle brush as a suitable candidate for EE in the feedlot environment.

# 6. APPENDIX

**Table 2.1 CAB Abstracts (Ovid) search details.**

| | |
|---|---|
| 1. | exp beef cattle/ |
| 2. | (beef adj2 (cattle or cow* or bull)).ti,ab. |
| 3. | or/1-2 |
| 4. | exp calf housing/ or exp housing/ or exp cattle housing/ |
| 5. | (housing or barn* or pasture* or hill* or feedlot*).ti,ab. |
| 6. | or/4-5 |
| 7. | 3 and 6 |
| 8. | exp animal welfare/ |
| 9. | (welfare* or wellbeing).ti,ab. |
| 10. | or/9-10 |
| 11. | 7 and 10 |
| 12. | limit 11 to English language |

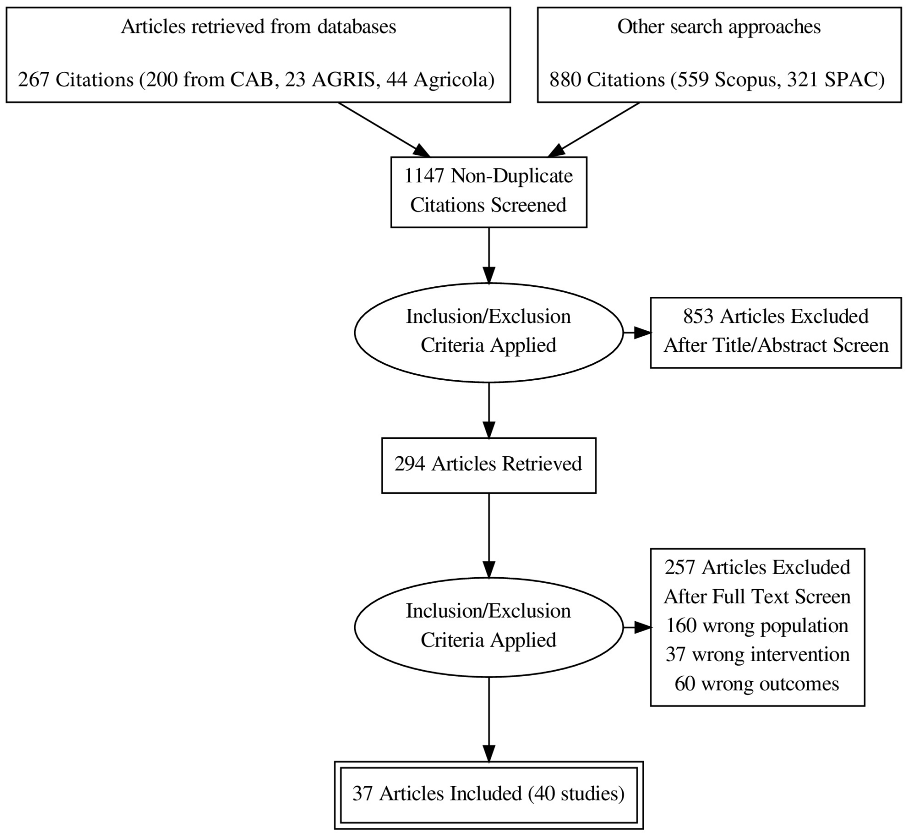


**Figure 2.1 PRISMA flowchart depicting article inclusion of beef cattle housing studies measuring animal welfare criteria.**

**Table 2.2 Population parameters of the studies evaluated. Shown are the descriptions or values provided by the original authors of the articles these studies were chosen from.**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Andrighetto (1999); *Italy* (16) | Housing system | Crates; Pens | Veal | 102 days | 34 | Bull calves (< 1 year) | Holstein | Yes |
| Blaine (2011); *South Africa* (31) | Shade | Feedlot | Fattening | 36 days | 146 | Bull; Steer (< 1 year) | Bonsmara crossbred | Yes |
| Blumetto (2017); *Uruguay* (13) | Housing system | Pasture; Feedlot | Fattening | 133 days | 48 | Steer (< 1 year) | Holstein | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Bond (1975); *USA* (6) | Shade | Feedlot | Fattening | 86 days | 112 | Bull (Not provided ) | Red Poll; Brown Swiss; Simmental and Hereford crossbred; Simmental and Angus crossbred; Limousin and Hereford crossbred; Limousin and Angus crossbred | No |
| Bond (1975); *USA* – Continued (6) | Shade | Feedlot | Fattening | 84 days | 120 | Bull (Not provided ) | Simmental and Hereford crossbred; Simmental and Angus crossbred; Limousin and Hereford crossbred; Limousin and Angus crossbred | No |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Braghieri (2011); *Italy* (10) | Housing system | Pasture; Feedlot | Fattening | 6 months | 12 | Bull (< 1 year) | Podolian | Yes |
| Brown-Bandl (2005); *USA* (29) | Shade | Feedlot | Fattening | 37 days | 8 | Steer (Not provided ) | Crossbred (¼ Angus, ¼ Hereford; ¼ Pinzsauer; ¼ Red Poll) | Yes |
| Brscic (2015); *Italy* (23) | Floor type | Feedlot | Fattening | 9 months | 326 | Bull (Not provided ) | Charolais; Limousin | Yes |
| Brscic (2015); *Italy* (35) | Floor type | Feedlot | Fattening | 1 month | 1440 | Bull (Not provided ) | Charolais and French crossbred | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Brscic (2015); *Italy* – Continued (35) | Floor type | Feedlot | Fattening | 4 months | 1800 | Bull (Not provided) | Charolais and French crossbred | Yes |
| Cozzi (2005); *Italy* (36) | Floor type | Feedlot | Fattening | 7 months | 1,338 | Bull (Not provided) | Charolais | Yes |
| Cozzi (2013); *Italy* (37) | Floor type | Feedlot | Fattening | 7 months | 48 | Bull (1 – 2 years) | Charolais and Aubrac crossbred | Yes |
| Earley (2015); *Ireland* (38) | Floor type | Feedlot | Fattening | 105 days | 240 | Heifer (1 – 2 years) | Continental cross; Holstein | Yes |
| Earley (2017); *Ireland* (39) | Floor type | Feedlot | Fattening | 7 months | 360 | Steer (Not provided) | Continental crossbred | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Elmore (2005); *USA* (26) | Floor type | Feedlot | Fattening | 3 months | 48 | Steer (< 1 year) | Angus cross | Yes |
| Ferrante (1999); *Italy* (15) | Housing system | Crates; Pens | Veal | Not provided | 24 | Bull calves (< 1 year) | Holstein | Yes |
| Fisher (1997); *Ireland* (17) | Space allowance | Feedlot | Fattening | 104 days | 32 | Heifer (Not provided) | Charolais, Simmental and Hereford crossbred | Yes |
| Fisher (1997); *Ireland* (21) | Space allowance | Feedlot | Fattening | 140 days | 96 | Heifer (Not provided) | Simmental cross | Yes |
| Gaughan (2010); *Australia* (30) | Shade | Feedlot | Fattening | 120 days | 164 | Steer (1 – 2 years) | Angus | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Hagenmaier (2016); *USA* (32) | Shade | Feedlot | Fattening | 1 month | 1,395 | Steer; Heifer (Not provided) | Not provided; predominately black hided | Yes |
| Hickey (2003); *Ireland* (19) | Floor type; Space allowance | Feedlot | Fattening | 97 days | 75 | Steer (Not provided) | Holstein | No; Yes |
| Johnson (2011); *USA* (14) | Housing system | Hoop barn; Feedlot | Fattening | 20 months | 960 | Steer (Not provided) | Crossbred steers; predominately Angus | Yes |
| Keane (2015); *Ireland* (25) | Floor type | Feedlot | Fattening | 148 days | 72 | Bull (Not provided) | Simmental crossbred | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Keane (2017); *Ireland* (18) | Floor type; Space allowance | Feedlot | Fattening | 105 days | 240 | Heifer (1 – 2 years) | Crossbred | Yes |
| Keane (2018); *Ireland* (40) | Space allowance | Pasture; Feedlot | Fattening | 105 days | 120 | Steer (1 – 2 years) | Charolais crossbred; Limousin crossbred | Yes |
| Khongdee (2016); *Thailand* (41) | Modified roof | Barn | Fattening | 157 days | 10 | Heifer (2 – 3 years) | Hindu Brazil-Brahman crosses | Yes |
| Lowe (2001); *Ireland* (27) | Floor type | Feedlot | Fattening | 140 days | 60 | Steer (Not provided) | Continental cross | Yes |
| | Floor type | Feedlot | Fattening | 142 days | 80 | Steer (Not provided) | Continental cross | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housin g system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Magrin (2017); *Italy* (42) | Ventilation | Feedlot | Fattening | 98 days | 69 | Bull (Not provided) | Charolais | Yes |
| Mitlöhner (2002); *USA* (28) | Shade | Feedlot | Fattening | 121 days | 168 | Heifer (Not provided) | Angus crossbred; Charolais crossbred | Yes |
| Ninomiya (2009); *Japan* (33) | Enrichment | Feedlot | Fattening | 65 days | 20 | Steer (< 1 year) | Japanese black; Japanese Shorthorn | Yes |
| Platz (2007); *Germany* (24) | Floor type | Feedlot | Fattening | 1 year | 18 | Bull (< 1 year) | Holstein and Fleckvieh crossbred | Yes |
| Ruis-Heutineck (2000); *Netherlands* (20) | Floor type; Space allowance | Feedlot | Fattening | 11 months | 192 | Bull (< 1 year) | Piemontese x Black and White crossbred | Yes |

**Table 2.2 Continued**

| **First author (Year); *Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Tessitore (2009); *Italy* (43) | Floor type | Feedlot | Fattening | 15 months | 2,700 | Bull (< 1 year) | Charolais and French crossbred | Yes |
| Tuomisto (2008); *Finland* (7) | Housing system | Pasture; barn | Fattening | 11 months | 20 | Bull (< 1 year) | Hereford | Yes |
| Tuomisto (2015); *Finland* (11) | Housing system | Pasture; feedlot | Fattening | 62 days | 29 | Bull (1 – 2 years) | Hereford | Yes |
| Starvaggi Cucuzza (2014); *Italy* (12) | Housing system | Feedlot | Fattening | Not provided | 12 | Bull (< 1 year) | Piemontese | Yes |
| Wilson (2002); *USA* (34) | Enrichment | Feedlot | Fattening | 22 days | 30 | Heifer (1 – 2 years) | Charolais cross | Yes |

**Table 2.2 Continued**

| **First author (Year);** ***Country*** | **Housing feature evaluated** | **Housing system** | **Production stage** | **Length of experiment** | **Number of animals (n)** | **Cattle sex (Cattle age)** | **Cattle breed** | **Significant results** |
|---|---|---|---|---|---|---|---|---|
| Van Iaer (2015); *Belgium* (8) | Shade | Pasture | Cow-calf | 2 years | 30 | Cow (Ranged from 2 to 7 years) | Belgian Blue | No |
| Yang (2017); *South Korea* (44) | Floor type | Open barn | Fattening | 6 months | 12 | Steer; Heifer (< 1 year) | Hanwoo | Yes |

**Table 2.3 Author selected behavioral, health, physiological and production measures demonstrating the frequency of measures used in beef cattle housing studies. Number beside measure indicates how many studies in this systematic review used that metric.**

| **Behavior** | **Health** | **Physiology** | **Production** |
|---|---|---|---|
| Eating – 23 | Hygiene scores - 13 | Haemoglobin – 7 | Live weight - 29 |
| Lying - 22 | Lesions / swellings - 7 | Neutrophil – 6 | Average Daily Gain (ADG) - 19 |
| Standing - 21 | Hoof lesions – 6 | Red blood cell – 6 | Feed efficiency[1] - 12 |
| Allogrooming - 16 | Hairless patches - 5 | Cortisol – 5 | Carcass external fat[2] – 12 |
| Headbutt – 13 | Body Condition Score (BCS) - 4 | Lymphocyte – 5 | Dry Matter Intake (DMI) - 11 |
| Self-grooming - 13 | Bursitis - 4 | Platelet - 5 | Carcass conformation score[3] - 10 |
| Mounting - 12 | Lameness score - 4 | Basophil – 4 | Carcass fat score - 9 |
| Drinking - 11 | Percentage culls - 4 | Eosinophil – 4 | Carcass internal fat[4] - 9 |
| Ruminating - 11 | Panting score - 3 | Fibrinogen – 4 | Carcass weight - 9 |
| Agonistic / Aggression - 6 | Nasal discharge - 3 | Haptoglobin – 4 | Dressing percentage - 8 |
| Walking - 6 | Abnormal breathing - 1 | Hematocrit percentage – 4 | Kill-out proportion - 7 |
| Inactive - 5 | Abrasions – 1 | Leukocyte – 4 | Marbling score - 5 |

**Table 2.3 Continued**

| **Behavior** | **Health** | **Physiology** | **Production** |
|---|---|---|---|
| Tongue rolling – 5 | Coughing – 1 | Monocyte – 4 | Hot Carcass Weight (HCW) - 4 |
| Utilizing shade – 5 | Joint swelling - 1 | | Water intake - 3 |
| Intentions to lie down - 4 | Ocular discharge – 1 | | |
| Licking / manipulating objects - 4 | Percentage mortality - 1 | | |
| Slipping - 4 | Percentage treatments - 1 | | |
| Avoidance Distance at Feedrack (ADF) - 3 | | | |
| Abnormal lying down sequence - 2 | | | |
| Displacement – 2 | | | |
| Interaction with enrichment – 2 | | | |
| Grazing – 2 | | | |
| Temperament score - 1 | | | |

[1]Feed efficiency includes feed conversion ratio and F:G.

[2]Carcass external fat includes carcass fat score, fat thickness, mean subcutaneous fat depth, P8 fat, rib fat, 12th rib fat depth.
[3]Carcass conformation score includes USDA yield grade and EUROP class scale.
[4]Carcass internal fat includes kidney and channel fat weights, percentage kidney, pelvic and heart fat, perinephric and retroperitoneal fat.

**Table 2.4 Comparison of different beef cattle housing systems provided to beef cattle. The bolded housing system is the condition being evaluated in comparison to one or more additional housing systems. Inclusion of significant results was determined at *P* < 0.05. The + sign indicates a benefit, - sign indicates a drawback and +/- indicates a neutral finding, of the housing system in regards to beef cattle welfare status.**

**Confined feedlot**

Vs. Confined feedlot with access to pasture Vs. Pasture

- Engaged in negative interactions with conspecifics more (13)
- Engaged in headbutting more (13)
- Engaged in displacement behavior more (13)
- Pushed other cattle with their chest more (13)

**Feedlot with shelter**

Vs. Hoop barn

- Spent less time lying (14)
- Spent more time standing (14)
- Spent more time waking (14)

**Individual wooden crates**

Vs. group pens

+/- Self-groomed more frequently (16)

- Engaged in tongue playing more frequently (16)
- Greater % of cooking weight losses (16)
- Laid with all their legs bent more frequently (16)

**Individual wooden crates**

Vs. group pens

- Allogrooming less frequently (15)
- Lower EUROP scores (16)
- Lower color scores (16)
- Less redness scoring (16)
- Less yellowness scoring (16)
- Lower tenderness scores (16)
- Lower flavor scores (16)
- Lower amount of hemoglobin (16)
- Lower % of packed cell volume (16)
- Sham ruminated less frequently (16)

**Table 2.4 Continued**

**Loose barn**

Vs. Free range pasture

- \+ Greater final live weight (10)
- \+ Greater ADG (10)
- \+ Greater BCS (10)
- \+ Higher meat lightness values (10)
- \+ Higher levels of blood urea nitrogen (10)
- \+ Higher levels of alkaline phosphate (10)
- \+ Higher levels of serum phosphorous (10)
- \+ Traveled shorter distance (10)
- \+ Shorter duration of vocalization (10)
- \+ Shorter duration of walking (10, 11)
- \+ Shorter duration of mounting (11)
- \+ Shorter duration of lying (11)
- \+ Shorter duration of allogrooming (11)

**Loose barn**

Vs. Free range pasture

- \+ Spent more time feeding (10, 11)
- +/- Spent more time rubbing (11)
- \- Lower levels of calcium (10)
- \- Spent more time standing (10)
- \- Spent more time engaging in agonistic interactions (10)
- \- Spent less time foraging (11)
- \- Spent less time ruminating (11)
- \- Spent more time performing oral explorative and manipulative behaviors (10, 11)

**Pasture**

Vs. Confined feedlot Vs. Confined feedlot with access to pasture

- \+ Greater levels of urea mean concentration (13)
- \- Lower levels of alkaline phosphate mean concentration (13)

**Tie-stalls**

Vs. Loose housing

- \- Greater serum cortisol response (12)
- \- Greater levels of serum corticosterone (12)
- \- Greater levels of fecal corticosterone (12)
- \- Greater levels of serum lysozyme (12)
- \- Greater levels of total serum protein (12)

**Table 2.5 Comparison of different space allowances ($m^2$/animal) provided to beef cattle across different housing types. The bolded space allowance is the condition being compared to one or more space allowances. Inclusion of significant results was determined at *P* < 0.05. The + sign indicates a benefit, - sign indicates a drawback and +/- indicates a neutral finding, of the space allowance in regards to beef cattle welfare status.**

**1.5$m^2$**

Vs. 2.0$m^2$ Vs. 2.5$m^2$
- Shorter duration of each lying bout (21)

Vs. 2.0$m^2$ Vs. 2.5$m^2$ Vs. 3.0$m^2$
- Greater kill out proportion (21)
- Reduced final body weight (21)
- Reduced ADG (21)
- Shorter duration of lying (21)

Vs. 2.0$m^2$ Vs. 3.0$m^2$
- Shorter duration of rumination (21)

Vs. 2.0$m^2$ Vs. 3.0$m^2$ Vs. 4.0$m^2$
- Shortest duration of lying (19)

Vs. 3.0$m^2$
- Higher kill-out proportion (17)
- Shorter duration of lying (17)

Vs. 3.0$m^2$ Vs. 4.0$m^2$
- Reduced carcass weight (19)
- Reduced daily carcass gain (19)

Vs. 4.0$m^2$
- Fewer positive social interactions (19)
- Higher feed conversion ratio (19)

**2.0$m^2$**

Vs. 2.5$m^2$ Vs. 3.0$m^2$
- Highest feed conversion ratio (40)
- Lowest slaughter weight (40)
- Lowest ADG (40)
- Lowest carcass weight (40)
- Lowest mean lying time (40)
- Lowest number of animals self-grooming (40)

Vs. 4.0$m^2$
- Higher feed conversion ratio (19)

**2.5$m^2$**

Vs. 1.5$m^2$

\+ Greater carcass weights (21)

**Table 2.5 Continued**

**$3.0m^2$**

Vs. $1.5m^2$

- \+ Greater carcass weight (17)
- \+ Greater live weight (17)
- \+ Greater number of positive social interactions (17)
- \+ Higher plasma NEFA concentrations (17)
- \+ Higher daily live weight gain (17)
- \- Higher mean pre-ACTH cortisol concentrations (17)
- \- Higher peak post-ACTH cortisol concentrations (17)

Vs. $1.5m^2$ Vs. $2.5m^2$

- \- Shorter duration of eating (19)

Vs. $2.0m^2$

- \+ Lower kill out proportion (19)

**$3.0m^2$**

Vs. $4.0m^2$

- \- Higher feed conversion ratio (19)

**$4.2m^2$**

Vs. $2.0m^2$

- \+ Higher percentage of lying (20)
- \+ Reduction of abnormal behavior (20)

**$4.5m^2$**

Vs. $3.0m^2$ Vs. $6.0m^2$

- \+ Greatest ADG (18)
- \+ Lowest feed conversion ratio (18)

**Table 2.6 Comparison of different flooring types provided to beef cattle. The bolded floor type is the condition being evaluated in comparison to one or more additional floor types. Inclusion of significant results was determined at $P < 0.05$. The + sign indicates a benefit, - sign indicates a drawback and +/- indicates a neutral finding, of the floor type in regards to beef cattle welfare status.**

**Deep litter**

Vs. Fully slatted concrete floor
- Greater avoidance distance from feed rack (43)
- Greater % of agonistic interactions (43)
- Greater % of mounting events (35, 43)
- Greater % of bulls standing (43)
- Greater % of animals eating (38)
- Greater % of animals headbutting (38)
- Greater prevalence of nasal discharge (35)
- Higher hygiene scores (35)

Vs. Natural rubber structure (EasyFix)
+/- Greater % of animals eating (38)

Vs. Rubber Mat (Irish Custom Extruders, LTD)
+/- Greater % of animals eating (38)

**Flat concrete floor**

Vs. Partially sloped floor
- Higher Ministry of Agriculture, Fisheries and Food (MAFF) hygiene score (36)
- Higher ventral part hygiene score (36)

**Foam structure rubber mat (EVA)**

Vs. Fully slatted concrete floor
\+ Higher live weight gain (39)

Vs. Natural rubber structure (EasyFix)
\+ Greater live weight gain (39)

**Fully slatted concrete floor**

Vs. Deep litter
\+ Greater percentage of cohesive interactions (43)
\+ Reduced amount of hoof lesions (38)
\+ Longer duration of lying (43)
- Greater prevalence of bursitis (35)
- Greater prevalence of hairless batches (35)
- Greater prevalence of lesions / swelling (35)
- Greater % of early culling (35)

Vs. Foam structure rubber mat (EVA)
\+ Greater % of time spent drinking (39)

**Table 2.6 Continued**

**Fully slatted concrete floor**

Vs. Foam structure rubber mat (EVA)
- \+ Lowest number of hoof lesions (39)
- \- Reduced % of time spent eating (39)

Vs. Fully slatted rubber mats
- \+ Cleaner pen (26)
- \+ Greater % of animals resting (23)
- \+ Longer duration of lying (23, 24)
- \- Greater % of animals inactive (23)
- \- Greater prevalence of bursitis (23)
- \- Greater number of abnormal lying down behaviors (23)
- \- Greater number of times unsuccessfully lying down (23)
- \- Higher % of abnormal behavior (20)

Vs. Fully slatted rubber mats
- \- Higher skin lesion scores (24)
- \- Higher % animals treated for locomotor disorders (23)

Vs. Natural rubber structure (EasyFix)
- \+ Lower frequency of hoof lesions (38, 39)
- \+ Lower frequency of hoof overgrowth (38)
- \- Greater % of mounting behavior (38)

Vs. Outwintering pads
- \+ Greater % of time spent drinking (39)
- \- Lower % of animals eating (39)

Vs. Partially slatted rubber mats
- \- Longer duration of lying (24)
- \- Higher skin lesion scores (24)

Vs. Perforated concrete floors
- \- Greater number of slipping events (37)

Vs. Perforated rubber mats
- \+ Greater duration of lying behavior (37)
- \- Greater number of slipping events (37)
- \- Greater number of lying down attempts (37)

Vs. Rubber mat (Durapak Rubber Products)
- \+ Greater percentage of time spent drinking (39)
- \+ Fewer number of hoof lesions (39)
- \- Lower % of time spent eating (39)

Vs. Rubber Mat (Irish Custom Extruders, LTD)
- \+ Reduced amount of hoof lesions (38)
- \+ Reduced amount of hoof overgrowth (38)

Vs. Solid rubber mat – partial cover
- \+ Cleaner pen (26)

**Table 2.6 Continued**

**Fully slatted concrete floor**

Vs. Straw

+ Greater total serum protein (18)

**Fully slatted rubber mats**

Vs. Fully slatted concrete floor

+ Displayed more postural changes (26)
+ Greater % of animals eating (23)
+ Greater % of animals being active (23)
+ Greater final live weight (23)
+ Greater kidney and channel fat weights (25)
+ Greater hide weight (25)
+ Greater frequency of animals lying (20)
+ Higher live weight gain (25)
+ Higher ADG (23, 25)
+ Higher carcass gain (25)
+ Improved feed conversion ratio (25)
+ Less severe lesions (20)
+ Lower gait score (26)
+ Reduced hock swelling scores (26)
+ Reduced knee swelling (26)
- Greater amount of hoof lesions (25)
- Greater prevalence of hoof overgrowth (23)
- Greater number of mounting events (23)
- Greater number of chasing events (23)
- Greater number of headbutting events (23)

**Fully slatted rubber mats**

Vs. Solid rubber mat – partial cover

+ Cleaner pens (26)
+ Displayed more postural changes (26)
+ Lowest gait score (26)
+ Reduced knee swelling (26)
+ Reduced hock swelling scores (26)

Vs. Straw

+ Greater final live weight (20)
+ Higher live weight gain (20)
+ Less severe skin lesions (20)
- Greater amount of hoof lesions (25)

**Table 2.6 Continued**

**Natural rubber structure (EasyFix)**
- Vs. Deep litter
  - \+ Greater % of animals lying (38)
  - \- Greater level of hoof erosion (38)
  - \- Greater hoof overgrowth (38)
- Vs. Foam structure rubber mat (EVA)
  - \+ Greater % of animals lying (38)
  - \- Lower % of time spent eating (39)
- Vs. Fully slatted concrete floor
  - \+ Greater % of animals lying (38)
  - \- Greater % of animals headbutting (38)
  - \- Greater level of hoof erosion (38)
- Vs. Rubber mat (Durapak Rubber Products)
  - \+ Greater % of animals lying (38)
  - +/- Lower % of time spent eating (39)
- Vs. Outwintering pads
  - \+ Greater % of animals lying (38)
  - +/- Lower % of time spent eating (39)

**Outwintering pads**
- Vs. Foam structure rubber mat (EVA)
  - \+ Higher live weight gain (39)
  - \+ Higher dry matter intake (39)
- Vs. Foam structure rubber mat (EVA)
  - \+ Greater % time spent eating (39)
  - \- Higher hygiene scores (39)
  - \- Lower % of lying time (39)
  - \- Lower % of time spent drinking (39)
- Vs. Fully slatted concrete floor
  - \+ Higher live weight gain (39)
  - \+ Higher dry matter intake (39)
  - \+ Greater % time spent eating (39)
  - \- Higher hygiene scores (39)
  - \- Lower % of lying time (39)
  - \- Lower % of time spent drinking (39)
- Vs. Natural rubber structure (EasyFix)
  - \+ Higher live weight gain (39)
  - \+ Higher dry matter intake (39)
- Vs. Natural rubber structure (EasyFix)
  - \+ Greater % time spent eating (39)
  - \- Higher hygiene scores (39)
  - \- Lower % of lying time (39)

**Table 2.6 Continued**

**Outwintering pads**

Vs. Natural rubber structure (EasyFix)

- Lower % of time spent drinking (39)

Vs. Rubber mat (Durapak Rubber Products)

+ Higher live weight gain (39)
+ Higher dry matter intake (39)
+ Greater % time spent eating (39)
- Higher hygiene scores (39)
- Lower % of lying time (39)
- Lower % of time spent drinking (39)

**Perforated rubber mats**

Vs. Fully slatted concrete floor

+ Higher ADG (37)
- Greater number of mounting events (37)

Vs. Straw

- Higher hygiene scores (27)

Vs. Strips of rubber secured to slats

- Higher hygiene scores (27)

**Rubber mat (Durapak Rubber Products)**

Vs. Fully slatted concrete floor

+ Higher live weight gain (39)

Vs. Natural rubber structure (EasyFix)

+ Higher live weight gain (39)

**Rubber Mat (Irish Custom Extruders, LTD)**

Vs. Deep litter

+ Greater % animals lying (38)
+ Greater % grooming behavior (38)
+ Lower hygiene scores (38)
- Greater % animals mounting (38)
- Greater level of hoof erosion (38)

Vs. Fully slatted concrete floor

+ Greater % animals lying (38)
+ Lower hygiene scores (38)
- Greater level of hoof erosion (38)

Vs. Natural rubber structure (EasyFix)

+ Greater % grooming behavior (38)
+ Higher hygiene scores (38)
- Greater % animals mounting (38)

**Table 2.6 Continued**

**Sawdust**

Vs. Rice husks

+ Greater final body weight (44)
- Greater amount of aggressive behavior (44)

Vs. Wood shavings

- Greater frequency of aggressive behavior (44)

**Solid rubber mat – partial cover**

Vs. Fully slatted concrete floor

+ Spent more time lying (26)
+ Spent more time grooming (26)
- Higher hygiene scores (26)
- Increased skin lesions (26)

Vs. Fully slatted rubber mats

- Higher hygiene scores (26)
- Increased lesions (26)

**Straw**

Vs. Flat concrete floor

+ Lowest hygiene scores (27)

Vs. Fully slatted concrete floor

+ Greater lying frequency (20)
+ Greater slaughter weight (18)
+ Greater % of animals lying (18)
+ Higher ADG (18)
+ Higher feed conversion ratio (18)
+ Higher carcass weight (18)
+ Higher hide weight (18)

Vs. Fully slatted rubber mats

+ Lowest hygiene scores (27)
+ Greatest lying frequency (20)

**Table 2.7 Evaluation of shade in beef cattle housing studies on its impact to animal welfare. The shade treatment is being compared to a control environment that did not provide cattle with shade. Inclusion of significant results was determined at *P* < 0.05. The + sign indicates a benefit and - sign indicates a drawback of providing shade to beef cattle housing units and its impact on beef cattle welfare.**

Shade

Vs. No shade

+ Fewer dark cutting carcasses (28)
+ Greater final weights (28, 30, 31)
+ Greater hip height (30)
+ Greater DMI (28, 30, 32)
+ Greater ADG (30)
+ Greater G:F (30)
+ Greater dressing percentage (32)
+ Heavier HCW (30, 31)
+ Higher USDA yield grade (28)
+ Higher % of lymphocytes (28)
+ Lower respiration rates (28, 29)
+ Lower mean panting scores (30, 31)
+ Lower % of neutrophils (28)
+ Lower neutrophil:lymphocyte ration (28)
+ Increased proportion of animals feeding (31)
- Lower dressing percentage (30)

**Table 2.8 Evaluation of different housing features used in beef cattle housing in comparison to other features. The first housing feature listed is being evaluated in comparison to another or multiple other housing features. Inclusion of significant results was determined at *P* < 0.05. The + sign indicates a benefit, - sign indicates a drawback and +/- indicates a neutral finding, of the housing feature in regards to beef cattle welfare status.**

**Housing feature evaluated:**

**Enrichment**

- Enrichment (brush and log)
  - Vs. Control
    - \+ Greater percentage of time spent eating (33)
- Milk-scent releasing device
  - Vs. Lavender-scent releasing device Vs. Blank-scent releasing device
    - \+ Used more often (34)
- Rubbing devices
  - Vs. Milk-scent releasing device Vs. Lavender-scent releasing device Vs. Blank-scent releasing device
    - \+ Higher frequency of interaction with device (34)
    - \+ Higher duration of interaction with device (34)

**Roofing**

- Modified roof
  - Vs. Control
    - \+ Higher ADG (41)
    - \+ Lower rectal temperatures (41)

**Ventilation**

- Ceiling van
  - Vs. Control
    - \+ Lower hygiene scores (42)
    - \+ Reduced abnormal breathing (42)
    - \- Greater amount of mounting events (42)

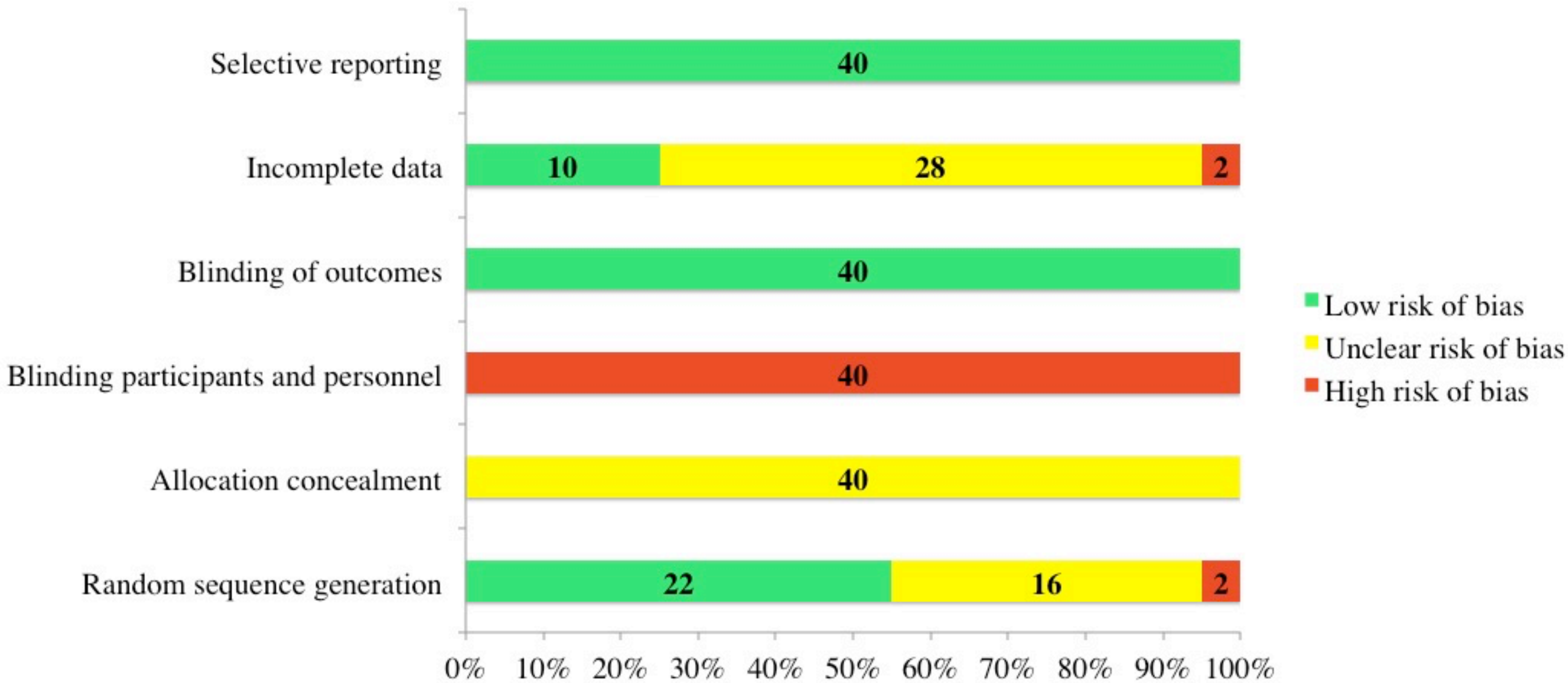


**Figure 2.2 Results of the Cochrane Risk of Bias analysis conducted on all studies by two trained observers.**

**Table 3.1 Ingredient and nutrient composition of steam-flaked corn based finishing diets with 5%, 10% or 15% corn stalk inclusion on a dry matter basis.**

| | % Corn stalk inclusion[1] | | |
|---|---|---|---|
| Item, % DM basis | 5% | 10% | 15% |
| Corn Stalks | 5 | 10 | 15 |
| Steam Flaked Corn | 55.95 | 55.75 | 55.3 |
| Wet corn gluten feed | 30 | 25 | 20.2 |
| Supplement premix | 3.5 | 3.5 | 3.5 |
| Urea | 0.4 | 0.7 | 1 |
| Limestone | 1.45 | 1.15 | 0.9 |
| Corn Oil | 3.7 | 3.9 | 4.1 |
| Calculated nutrient values | | | |
| DM, % | 71.91 | 73.43 | 74.96 |
| CP, % | 14.53 | 14.22 | 13.93 |
| NDF, % | 20.59 | 21.97 | 23.47 |
| Ether extract, % | x | x | x |
| Ca, % | 0.79 | 0.73 | 0.67 |
| P, % | 0.58 | 0.53 | 0.47 |
| S, % | 0.21 | 0.19 | 0.17 |
| ME, Mcal/kg | 2.69 | 2.59 | 2.51 |
| $NE_m$, Mcal/kg | 1.77 | 1.68 | 1.61 |
| $NE_g$, Mcal/kg | 1.14 | 1.07 | 1.00 |

[1]5% = 5% corn stalks with 30% wet corn gluten feed; 10% = 10% corn stalks with 25% wet corn gluten feed; 15% = 15% corn stalks with 20% wet corn gluten feed

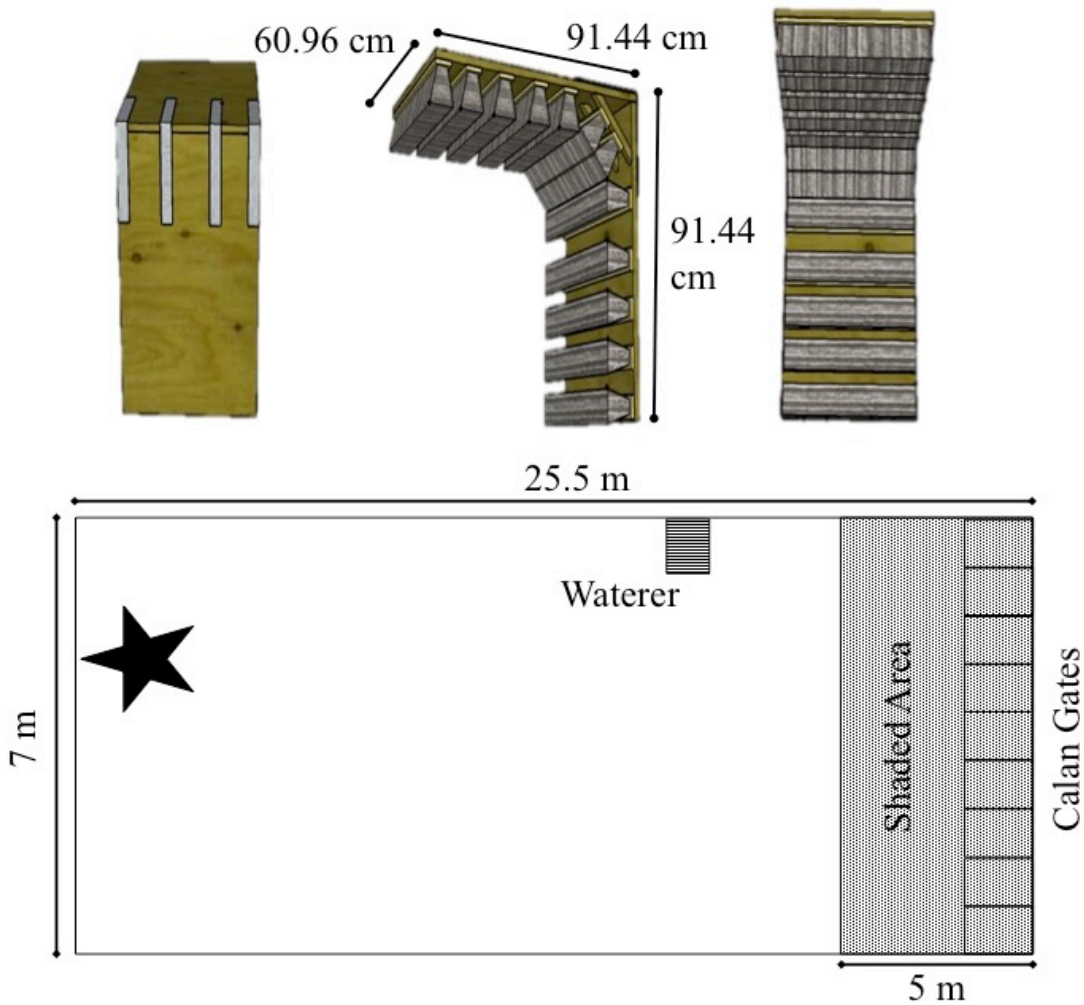


**Figure 3.1 Environmental enrichment "L-shaped" brush design welded to furthest fence line from feed bunk for treatment condition. Star indicates brush placement in pen relative to other housing features.**

**Table 3.2 Hair shedding scoring system Gray et al. (2011).**

| Hair Shedding Score | Definition |
|---|---|
| 5 | Full winter coat (0% shed) |
| 4 | Coat exhibits initial shedding (25% shed) |
| 3 | Coat is halfway shed (50% shed) |
| 2 | Coat is mostly shed (75% shed) |
| 1 | Slick, short summer coat (100% shed) |

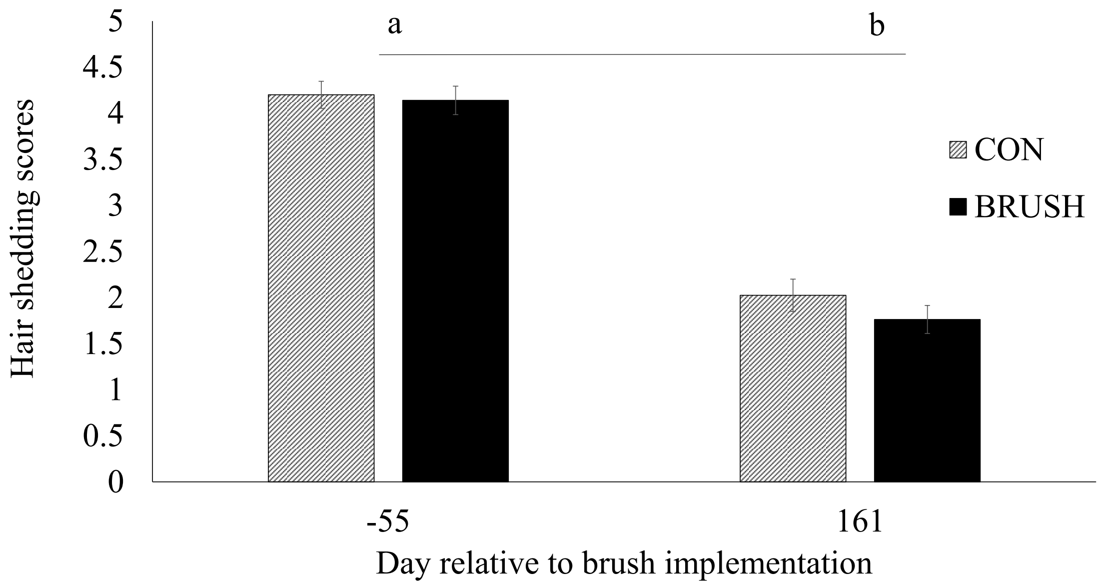


**Figure 3.2 Hair coat shed scores for cattle upon feedlot entry in November and at the time of departure from feedlot for the heavy weight block in June. Research day had a significant impact on hair coat shed scores (*P* < 0.0001).**

**Table 3.3 Effect of environmental enrichment on production traits**

| | Enrichment Treatment[1] | | | |
|---|---|---|---|---|
| Item | CON | BRUSH | SEM | *P*-value |
| Steers, *n* | 26 | 25 | | |
| DOF[2] | 223 | 223 | | |
| *Animal performance* | | | | |
| Initial SBW[3], kg | 295 | 285 | 4 | 0.57 |
| ADG, kg/d | 1.31 | 1.28 | 0.05 | 0.95 |
| DMI, kg/d | 8.18 | 8.07 | 0.22 | 0.85 |
| G:F | 0.163 | 0.160 | 0.007 | 0.880 |
| *Carcass adjusted performance[4]* | | | | |
| Final SBW[3], kg | 581 | 575 | 14 | 0.91 |
| ADG, kg/d | 1.31 | 1.29 | 0.07 | 0.77 |
| G:F | 0.074 | 0.074 | 0.005 | 0.936 |
| *Carcass data* | | | | |
| HCW, kg | 368 | 368 | 10 | 0.93 |
| Dressing percentage, % | 64.4 | 63.6 | 2.2 | 0.70 |
| Adjusted fat thickness, cm | 1.11 | 1.23 | 0.11 | 0.29 |
| Rib eye area, $cm^2$ | 91.0 | 92.9 | 2.6 | 0.54 |
| Marbling score | 296 | 291 | 17 | 0.82 |
| KPH, % | 2.0 | 1.9 | 0.07 | 0.08 |
| Choice or greater, % | 44.4 | 50.0 | 0.1 | 0.60 |
| Select or less, % | 55.6 | 50.0 | 0.1 | 0.61 |
| Normal livers, % | 85.2 | 79.2 | 0.1 | 0.58 |
| Abscessed livers, % | 14.8 | 12.5 | 0.1 | 0.82 |

[1]CON = Control; BRUSH = Environmental enrichment provided in the form of a cattle brush
[2]DOF = Days on feed; Block 1 = 209 and Block 2 = 237
[3]SBW = Shrunk BW. All BW measurements calculated with a 4% shrink.
[4]Carcass adjusted performance. Final SBW calculated as HCW/overall average dressing percentage (63.64%). Carcass-adjusted ADG calculated as (carcass-adjusted SBW – initial BW)/DOF. Carcass-adjusted G:F calculated as (carcass-adjusted ADG/average DMI).

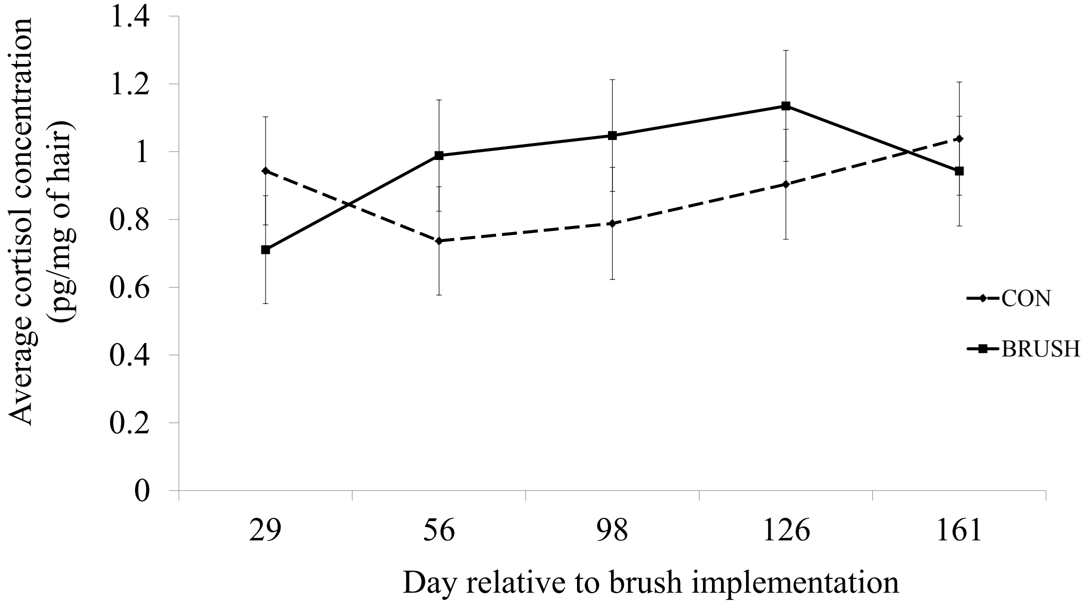


**Figure 3.3 Average cortisol concentration (pg/mg of hair) over time in the feedlot for cattle that were provided environmental enrichment and those that were not. There was no significant difference between treatments for cortisol concentration over time ($P$ > 0.05).**

**Table 4.1 Behavioral ethogram for behavioral data collection of feedlot cattle utilized by observers to determine either the amount of cattle in a pen that perform the following behaviors through scan sampling or the frequency and duration of behaviors that occurred through continuous sampling from 0800 to 1730 on d -2, -1, 0, 1, 2, 4, 8, 16, 32 and 64.**

| Behavior | Definition |
| --- | --- |
| Scan sampling | |
| Drinking | Steer has head in water trough |
| Feeding | Steer has head in feeder |
| Lying | Steer is recumbent, not supported by legs |
| Other | Steer is performing other behavior such as locomotion or standing |
| Continuous sampling | |
| Allogroom | Mouth of one steer on the body of another. Characterized by repetitive back-and-forth head movements performed by the actor in direct contact with the recipient. |
| Bar Licking | Mouth of one steer in direct contact with bars of pen |
| Headbutt | Head of steer connects with body of another |
| Kicking | Leg of steer connects with body of another |
| Mounting | Steer positions body on top of another subject's topline |
| Tongue Rolling | An open mouth with extended tongue repeatedly moving in and out and/or side-to-side. Characterized by repetitive side-to-side head motion. |
| Utilizing Brush | Any part of steer's body interacting with the brush |

**Table 4.2 Daily behavioral profile of feedlot steers housed in pens either with environmental enrichment (BRUSH) or without (CON). All values are presented as mean +/- standard error. Minimum and maximum values are presented in parentheses.**

| | Enrichment Treatment[1] | |
|---|---|---|
| Item | CON | BRUSH |
| *Scan sampling* | | |
| Lying, proportion of pen | 0.37 ± 0.07<br>(0 – 1) | 0.38 ± 0.07<br>(0 – 1) |
| Feeding, proportion of pen | 0.12 ± 0.03<br>(0 – 0.78) | 0.13 ± 0.04<br>(0 – 0.89) |
| Drinking, proportion of pen | 0.02 ± 0.01<br>(0 – 0.44) | 0.02 ± 0.01<br>(0 – 0.89) |
| Other, proportion of pen | 0.46 ± 0.07<br>(0 – 1) | 0.46 ± 0.07<br>(0 – 1) |
| *Continuous sampling* | | |
| Headbutts, counts | 50.02 ± 3.77<br>(1 – 625) | 37.98 ± 2.43<br>(1 – 253) |
| Kicks, counts | 0.06 ± 0.01<br>(0 – 1) | 0.10 ± 0.03<br>(0 – 6) |
| Mounts, counts | 0.96 ± 0.10<br>(0 – 10) | 0.81 ± 0.10<br>(0 – 13) |
| Allogrooming bouts, counts | 7.00 ± 0.53<br>(0 – 44) | 4.80 ± 0.47<br>(0 – 52) |
| Allogrooming duration, seconds | 325.25 ± 29.45<br>(0 – 2,742.75) | 212.14 ± 21.87<br>(0 – 1,926.84) |
| Bar licking bouts, counts | 3.85 ± 0.33<br>(0 – 30) | 2.25 ± 0.26<br>(0 – 37) |
| Bar licking duration, seconds | 159.13 ± 16.19<br>(0 – 1,842.22) | 85.70 ± 11.73<br>(0 – 1,459.98) |
| Tongue rolling bouts, counts | 9.06 ± 0.64<br>(0 – 68) | 11.37 ± 0.90<br>(0 – 100) |
| Tongue rolling duration, seconds | 187.19 ± 14.27<br>(0 – 1,356.22) | 234.06 ± 22.09<br>(0 – 2,557.22) |
| Brush usage bouts, counts | - | 4.15 ± 0.27<br>(0 – 22) |

**Table 4.2 Continued**

| | Enrichment Treatment[1] | |
|---|---|---|
| Item | CON | BRUSH |
| *Continuous sampling continued* | | |
| Brush usage duration, seconds | - | 464.31 ± 38.27 (0 – 3,297.28) |
| *Rumination collar, per day* | | |
| Activity duration, minutes | 512.05 ± 3.90 (383 – 740) | 495.42 ± 4.08 (329 – 768) |
| Rumination duration, minutes | 392.88 ± 6.58 (44 – 625) | 408.76 ± 6.73 (123 – 632) |

[1]CON = Control; BRUSH = Environmental enrichment provided in the form of a cattle brush

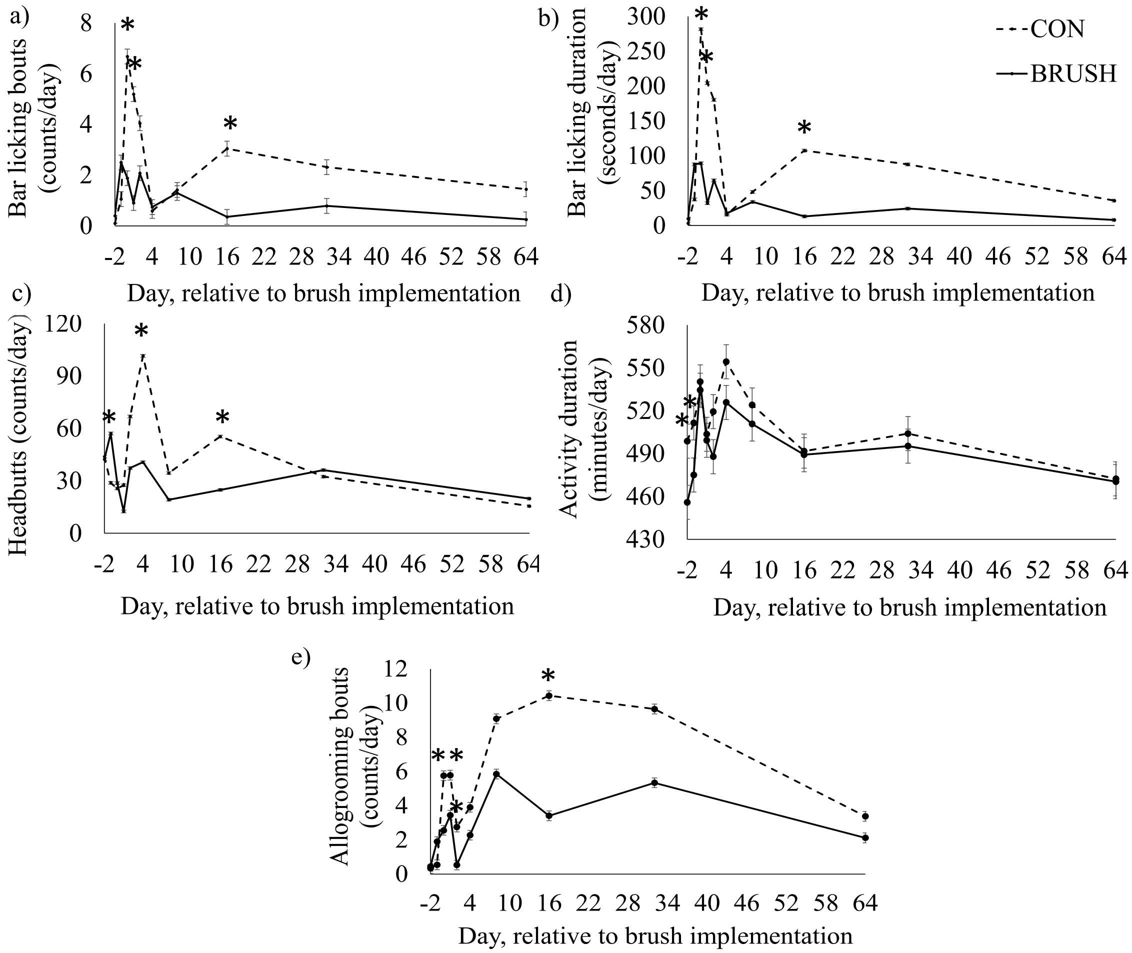


**Figure 4.1 Bar licking frequency (a), bar licking duration (b), headbutting frequency (c), activity duration (d), and allogrooming frequency (e) performed over time by feedlot steers housed in pens either with environmental enrichment (BRUSH) or without (CON). Asterisk denotes significant difference (*P* < 0.05) between treatment and control conditions within day.**

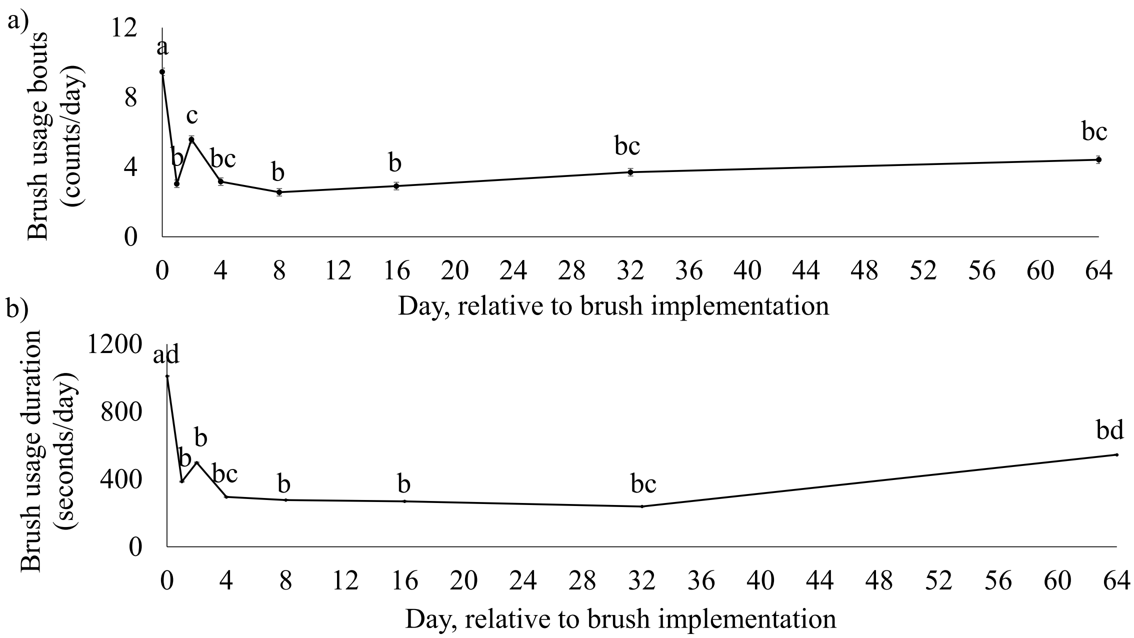


**Figure 4.2 Brush use frequency (a) and brush use duration (b) throughout the duration of the study. Different letters indicate significant differences (*P* < 0.05) among days.**

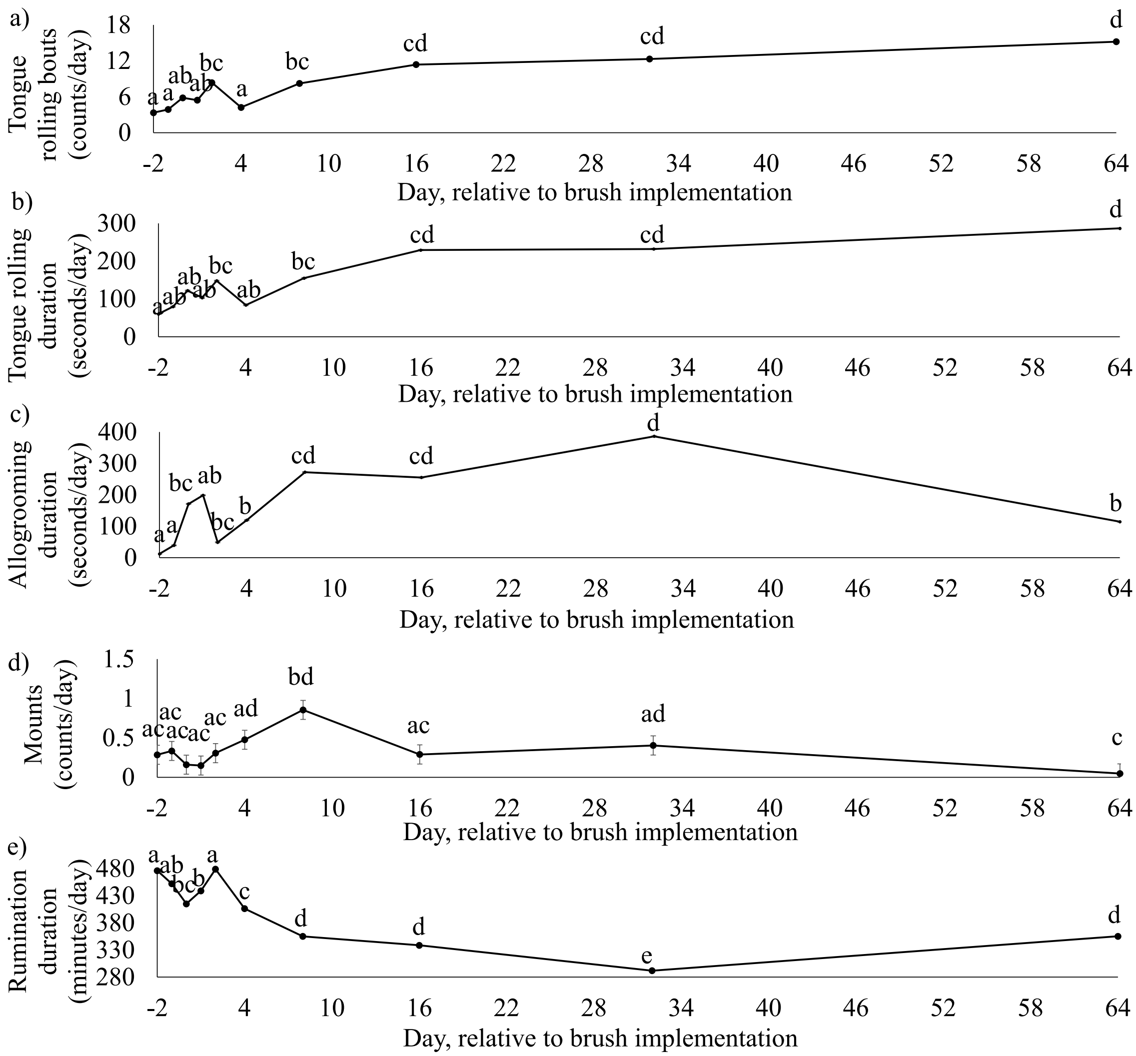


**Figure 4.3 Tongue rolling frequency (a), tongue rolling duration (b), allogrooming duration (c), mount frequency (d), and rumination duration (e) performed over time by feedlot steers. Different letters indicate significant differences (*P* < 0.05) among days.**

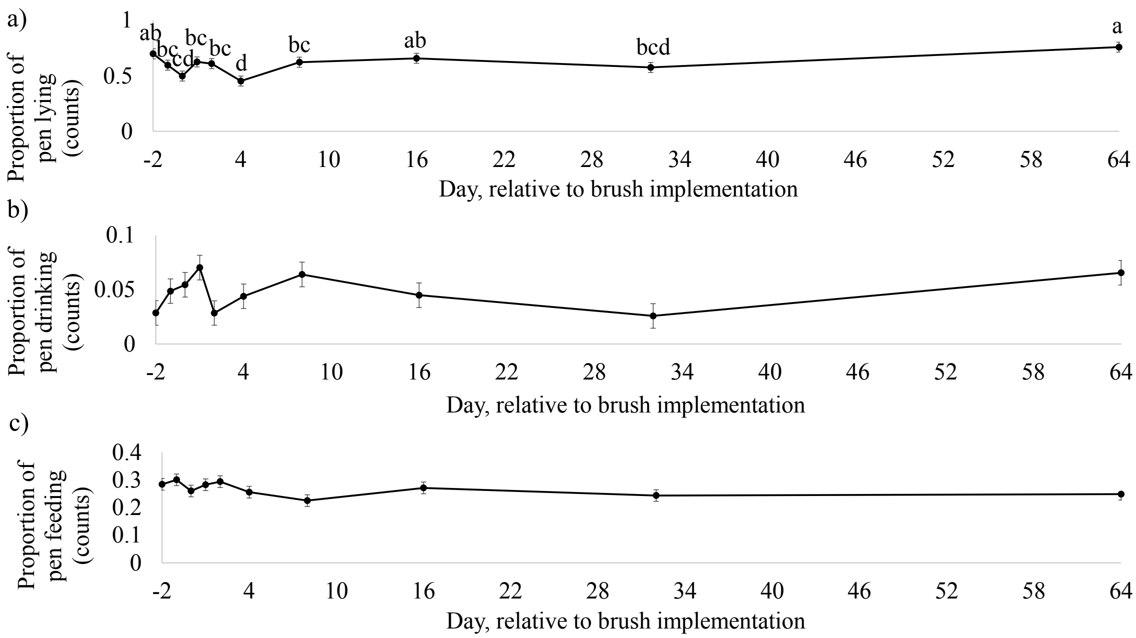


**Figure 4.4 Proportion of pen lying (a), drinking (b) and feeding (c) over time. Different letters indicate significant differences (*P* < 0.05) among days.**

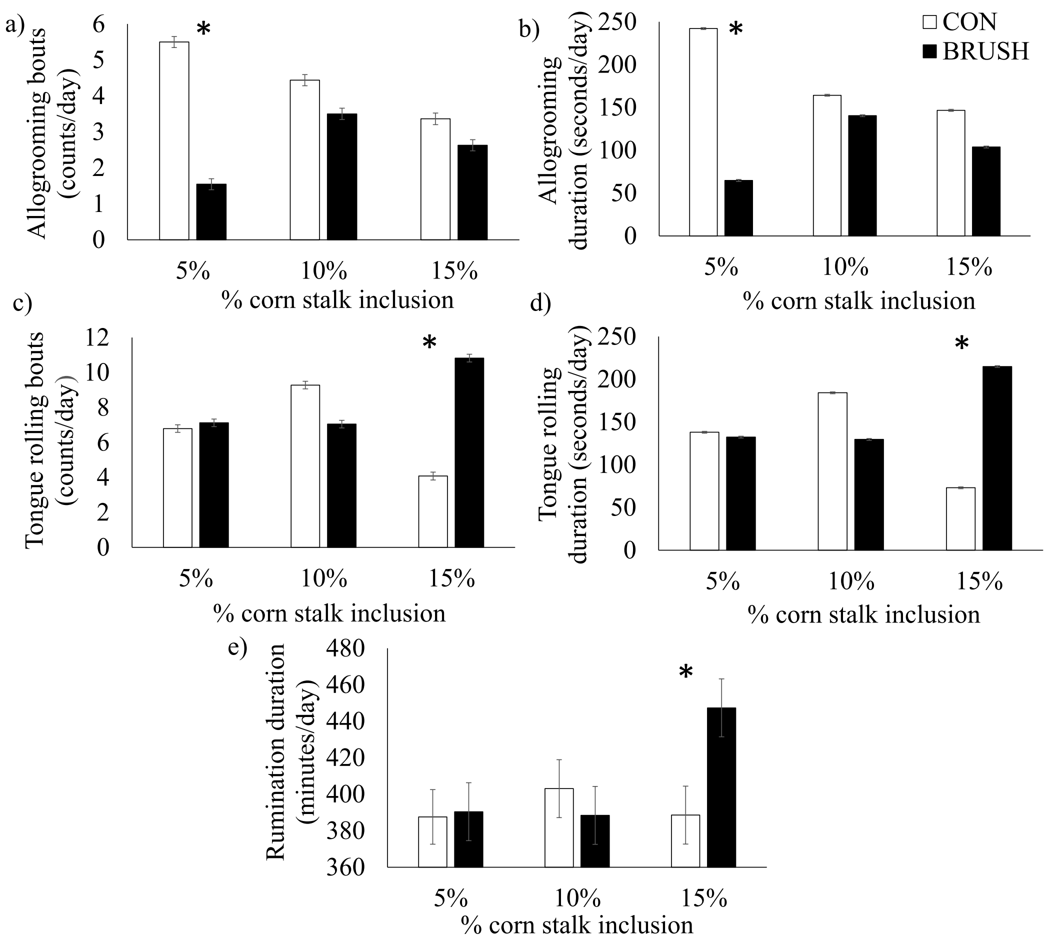


**Figure 4.5 Impact of environmental enrichment (BRUSH) and diet on allogrooming frequency (a), allogrooming duration (b), tongue rolling frequency (c), tongue rolling duration (d), and rumination duration (e) performed. Asterisk indicates significant differences (*P* < 0.05) between EE treatments within a diet.**